Developing a California Inventory for Industrial Applications of Perfluorocarbons, Sulfur Hexafluoride, Hydrofluorocarbons, Nitrogen Trifluoride, Hydrofluoroethers and Ozone Depleting Substances

Agreement Number 07-313

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March 2011

DISCLAIMER

ACKNOWLEDGMENTS

The analysis in this report benefited considerably from the efforts of many persons within and outside the Institute for Research and Technical Assistance (IRTA). I would particularly like to acknowledge the valuable contributions made by Jack Gerard and Frank Kunowski at Facilities Protection Systems, Cranston Sherley at CSI Fire Equipment Co, Inc. and Tom Cortina at the Halon Alternatives Research Corp. and the Halon Recycling Corp. I am grateful for the guidance provided by Ken Bowers of the California Air Resources Board. Finally, I am indebted to Holly Brown and Amy Blume for their assistance in preparing the document.

This Report was submitted in fulfillment of ARB Agreement Number 07-313 "Developing a California Inventory for Industrial Applications of Perfluorocarbons, Sulfur Hexafluoride, Hydrofluorocarbons, Nitrogen Trifluoride, Hydrofluoroethers and Ozone Depleting Substances" by the Institute for Research and Technical Assistance under the sponsorship of the California Air Resources Board. Work was completed as of March 31, 2011.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

As part of the California Air Resources Board's (CARB's) responsibilities under AB 32, the Global Warming Solutions Act of 2006, the agency sponsored projects focused on developing an inventory of greenhouse gases (GHGs) in California. This project, which is part of that effort, involved developing bottom up estimates of emissions of GHGs for 2010 and 2020 for solvent, fire protection and other applications. The approach used here relied on local air district permits and information from equipment installers and suppliers to generate emission estimates for solvents and fire protection equipment and the bank of agents in fire protection equipment. The results demonstrated that emissions will decline in both of the applications that were analyzed over the period because of trends already underway. Cumulative emissions from solvent and fire protection applications are estimated at 0.186 and 0.363 million metric tons of carbon dioxide equivalent respectively over the ten year period. Cumulative emissions from other applications that were analyzed are estimated at 0.017 million metric tons of carbon dioxide equivalent. The project also involved investigating non-GHG alternatives and alternatives that are reasonably cost effective were identified for most applications. CARB could adopt policies to reduce emissions further, particularly in solvent applications.

EXECUTIVE SUMMARY

Background

In 2006, the California Legislature passed AB 32, the Global Warming Solutions Act, which charges the California Air Resources Board (CARB) with developing and implementing a plan for the state of California for reducing emissions of greenhouse gases (GHGs) to 1990 levels by 2020. Part of CARB's work in developing the plan involves determining the inventory of many different types of GHGs with high global warming potentials (GWPs) used in a variety of applications in California. CARB sponsored this research as part of that effort. The Institute for Research and Technical Assistance (IRTA), a technical environmental nonprofit organization, performed the research. The focus of the project was to develop an inventory for the bank and emissions of GHGs used in solvent, fire protection and various other applications.

Methods

There are three solvent applications that rely on the use of GHGs, including film cleaning, vapor degreasing and disk lubing. Solvents used in these applications are hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), hydrofluoroethers (HFEs) and perfluorocarbons (PFCs). In film cleaning, one HCFC and HFEs are used by the movie industry to clean original negative and archived film during processing to remove fingerprints and particle contaminants. In vapor degreasing, an HCFC, HFEs and HFC solvents and their blends are used to remove various contaminants like oils, flux and particles from metal and plastic parts in general and precision cleaning. In disk lubing, PFC and HFE solvents act as carriers for a lubricant which is deposited on hard computer disks.

This project involved developing bottom up estimates of emissions from solvent applications. Using information from permits from local air districts in California and discussions with industry representatives, emissions from the three applications were developed for a baseline year, 2010, and were projected under a business as usual (BAU) scenario for 2020. Two alternative emissions projections were also developed to take into account other potential conditions and trends during the period. The analysis also involved investigating potential non-GHG alternatives and alternative processing methods for reducing emissions and estimating the cost of using them. For all three solvent applications, IRTA estimated cumulative emissions over the ten year period.

There are two fire protection applications that rely on the use of GHGs and these include fixed total flooding systems and portable fire extinguishers. GHG fire protection agents used in these applications include halons, an HCFC, various HFCs and a perfluoroketone. In total flooding systems, the GHGs are used mainly to protect expensive electronics equipment and data that could be destroyed in the event of a fire. Portable fire extinguishers are used in a variety of places including marine and aerospace facilities for local fire protection.

This project involved developing bottom up estimates of the "bank" of agents in fire protection equipment in the state in 2010, the baseline year. IRTA worked with system installers to estimate the number of systems and the types of GHGs used in California. It also involved developing projections of the 2020 bank under BAU conditions. Based on the size of the bank and losses from the equipment, estimates of 2010 and 2020 emissions were estimated. Two alternative scenarios for total flooding systems and portable extinguishers were developed for the size of the bank and emissions in 2020. The analysis also included analyzing and investigating the GHG alternatives and comparing the cost of using them. For both applications, IRTA also estimated cumulative emissions over the ten year period.

IRTA identified three other applications that rely on the use of stockpiled GHGs which are ozone depleting substances. The applications are dry cleaning of delicate garments and costumes in the movie industry, use of inert material in implantable devices by medical device manufacturers and cleaning of energized electrical equipment. For these three applications, IRTA analyzed potential alternatives, estimated the amount of stockpiled material and estimated cumulative emissions over the ten year period based on knowledge of the industries.

Results

The project results indicate that emissions of solvents from film cleaning will decline over the ten year period from 2010 to 2020 because of the trend to digital technology. Emissions from vapor degreasing will also decline because of a production ban for an HCFC with a relatively high GWP. Emissions from disk lubing are expected to remain constant over the period. Total solvent emissions will decline from about 0.028 to 0.011 million metric tons of carbon dioxide equivalent from 2010 to 2020. Cumulative emissions over the period from this application are estimated at 0.186 million metric tons of carbon dioxide equivalent. In all three applications, non-GHG and low GWP alternatives are available and cost effective.

The project results show that the size of the bank of GHGs in total flooding systems is high, nearly three million metric tons of carbon dioxide equivalent. Emissions from total flooding systems are expected to decline from 0.053 to 0.013 million metric tons of carbon dioxide equivalent from 2010 to 2020. Emissions from portable fire extinguishers are expected to also show a decline, from 0.006 to 0.005 million metric tons of carbon dioxide equivalent. In both applications, there will be a reduction in the availability of ozone depleting substances which have relatively high GWPs. In the total flooding system application, there is also a trend toward low GWP and non-GHG alternatives. Cumulative emissions from fire protection applications over the ten year period are estimated at 0.363 million metric tons of carbon dioxide equivalent. In the case of total flooding systems, non-GHG and low GWP alternatives are available and reasonably cost effective. For portable extinguishers, alternatives have not yet emerged.

For the three other applications that rely on stockpiled ozone depleting substances, the results indicate that cumulative emissions over the ten year period could amount to 0.017 million metric tons of carbon dioxide equivalent. Alternatives, in all three applications, are available.

The emissions estimates that were developed during the project were compared with estimates from EPA and two trade associations. For solvent applications, IRTA's emission estimates were much lower than those from EPA's Vintaging model. For fire protection applications, IRTA's HFC emission estimates compared reasonably well with trade association estimates and both of these estimates were somewhat lower than those of EPA's Vintaging model. For halons used in fire protection, IRTA's estimates differed from those of a trade association; they were higher than the trade association emission estimates for Halon 1211 and lower than the trade association emission estimates for Halon 1301.

Conclusions

This project illustrates that emissions from the solvent, fire protection and stockpiled applications analyzed here will decline over the next decade because of trends already underway. For most of the applications, alternatives are available and reasonably cost effective. CARB could adopt policies to reduce emissions further in a few of the applications.

Section 1. Introduction

Climate change is recognized by scientists as one of the most challenging issues over the next several decades. Emissions of greenhouse gases (GHGs) will increase substantially over the period. California is the twelfth largest source of GHGs in the world. The state is a major contributor to the problem and is also a leader in addressing environmental issues.

On June 1, 2005, California's Governor signed Executive Order S-3-05 which calls for a reduction of GHG emissions to 2000 levels by 2010, a reduction in GHG emissions to 1990 levels by 2020 and a reduction in GHG emissions to 80 percent below 1990 levels by 2050. In 2006, the California Legislature passed AB 32, the Global Warming Solutions Act, which charges the California Air Resources Board (CARB) with developing and implementing a plan for the state of California for reducing GHG emissions to 1990 levels by 2020.

The original focus for GHG emission reductions was on carbon dioxide, methane and, to a smaller extent, hydrofluorocarbons (HFCs). HFCs have been and will be used widely in a number of applications as alternatives to ozone depleting substances (ODSs) that have been or will be phased out over the next several years. CARB became aware that other substances including perfluorocarbons (PFCs), perfluoropolyethers (PFPEs), sulfur hexafluoride (SF6), nitrogen trifluoride (NF3), hydrofluoroethers (HFEs) and ODSs are being used and emitted in various industrial and commercial applications. All of these materials are GHGs and reductions in emissions may help CARB meet the requirements of AB 32.

CARB contracted with the Institute for Research and Technical Assistance (IRTA), a technical environmental nonprofit organization, to focus on certain applications where HFCs, HFEs, PFCs, PFPEs, SF6, NF3 and ODSs are used and emitted. Although emissions of these materials are lower than emissions of carbon dioxide, their Global Warming Potential (GWP) is much higher on a pound for pound basis. CARB sponsored separate projects which focus on GHG emissions from refrigeration and air conditioning and foam applications.

The aim of the project was to develop a bottom up inventory for the GHGs of concern used in California. Some of the applications that were included in the original workplan were addressed by CARB in pursuing AB 32 early action measures. A revised workplan adjusted for those changes in scope enabled IRTA to conduct more analyses comparing other estimates of GHG stockpiles and uses from industry groups and the U.S. EPA Vintaging Model. One of the early action measures undertaken by CARB, adopted in 2009, was the Semiconductor Perfluorocarbon Emissions Reduction Strategy. It addressed PFCs and PFPEs used in heat transfer processes and NF3 used by the semiconductor industry. In 2010, CARB adopted a regulation for SF6 used by electric utilities in electricity generation. The CARB consumer products group indicated that they would focus on GHG use in aerosol applications; this addressed the use of HFCs as propellants and HCFCs, HFCs and HFEs used in aerosol cleaning applications. After the project was initiated, IRTA determined there were no HCFC-22 production plants in California which indicated there are no HFC-23 emissions from such operations. IRTA also determined that the HCFCs used in handwipe applications were stockpiled uses of GHGs for electrical equipment cleaning. In the course of the project, IRTA also determined that use of PFCs and HFCs in one dry cleaning process was discontinued. The project areas of focus that remained included solvent, fire extinguishant and stockpiled use applications.

Table 1-1 summarizes the targeted GHGs and their potential applications. The table shows the general use category, the type of GHG, whether the GHG contributes to stratospheric ozone depletion and the more specific use of the GHG type. The use categories that were considered included solvents, fire extinguishing agents and a range of other uses.

In solvent applications, GHG emissions were estimated for three applications. The first application is film cleaning. Two GHG solvents, HFEs and an HCFC are used to clean movie film when it is processed in various ways. The studios and post production facilities that perform cleaning are concentrated in the Los Angeles area. The second application is vapor degreasing, which relies on halogenated solvents to clean metal and precision parts during manufacture and assembly operations. Three GHG solvents, an HCFC, HFEs and an HFC are used for this purpose. Companies using the vapor degreasing process are concentrated primarily in the Bay Area, the Los Angeles area and the San Diego area. The third application is disk lubing, where solvents act as carriers for a lubricant that is deposited on computer hard disks. Two GHG solvents, a PFC and an HFE, are used by two companies located in the Bay Area in northern California. IRTA relied on permit information from local California air districts and some discussions with suppliers to develop the estimates.

In fire protection applications, the size of the GHG "bank" and emissions were estimated for two applications. The first application is total flooding systems. These systems are used in instances where it is important to protect data or valuable equipment in case of fire. Such systems use two HFCs, Halon 1301, an ozone depleting substance and PFCs. The second application is portable fire extinguishers. These devices rely on one HFC and an HCFC and Halon 1211, both ozone depleting substances, to protect from fire. The fire protection agents are held in the total flooding systems and extinguishers and they form a bank of GHGs. With assistance from equipment installers, recyclers and trade associations, IRTA developed estimates of the bank and emissions in California. IRTA also estimated emissions from operations designed to recycle fire protection agents in California which is another source of GHG emissions.

There still exist stockpiles of certain ozone depleting substances that are also GHGs. IRTA identified three applications where stockpiles of a CFC and an HCFC are still used. These include dry cleaning of delicate garments, medical device manufacturing and energized electrical equipment cleaning. IRTA estimated emissions for these applications.

For solvent and fire protection applications, the approach involved estimating emissions for a baseline year, in this case 2010. Based on a business as usual (BAU) scenario, emissions were

Table 1-1 Targeted GHG Types and Potential Applications			
Use Category	GHG Type	ODS	Specific Use
Solvents	PFCs	no	heat transfer process
			dry cleaning process
	PFPEs		heat transfer process
	HCFCs	yes	handwipe cleaning
			aerosol cleaning
			film cleaning
			vapor degreasing
	HFCs	no	aerosol cleaning
			vapor degreasing
			disk lubing
	HFEs	no	aerosol cleaning
			heat transfer process
			film cleaning
			disk lubing
			dry cleaning process
	CFCs	yes	stockpile-dry cleaning
			stockpile-medical devices
Fire Extinguishants	PFCs	no	total flooding systems
			portable fire extinguishers
	HFCs	no	total flooding systems
			portable fire extinguishers
	HCFCs	yes	total flooding systems
			portable fire extinguishers
	Fluoroketone	no	total flooding systems
	Halons	yes	total flooding systems
			portable fire extinguishers
Other	SF6	no	electric utility applications
			semiconductor applications
	HFCs	no	aerosol propellants
	HFC-23	no	HCFC-22 production
	NF3	no	semiconductor applications

projected for 2020. In the case of fire protection, the size of the baseline and BAU projected were also estimated. In each application that was analyzed, two alternative emission projection scenarios were developed based on possible future behavior and trends. The project also involved investigating low GWP or non-GHG alternatives for all the targeted applications. In all cases, IRTA performed a cost analysis and comparison of using these alternatives.

Section 2 of this document presents the analysis for the three solvent applications that were analyzed. It summarizes the baseline and projected emission estimates and the cost comparison of the alternatives. Section 3 focuses on the analysis for fire protection applications. It summarizes baseline and projected bank and emission estimates and discusses the costs of using the alternatives. Section 4 provides a short discussion of the other stockpiled uses of GHGs and estimates emissions. Section 5 presents information on other estimates of emissions available from EPA and two trade associations. IRTA's emission estimates are compared with the emission estimates of these other sources. Finally, Section 6 summarizes the results and conclusions of the analysis.

Section 2. Greenhouse Gas Use in Solvent Applications

There are two major solvent applications where GHGs are used and one minor application. These solvents are much more expensive than other types of solvents and this limits their use to various high technology applications. The first application where GHG solvents are used is film cleaning in which contaminants are removed from movie film. The second application is vapor degreasing of certain critical metal and plastic parts. The third application is disk lubing. The three applications are discussed in more detail below.

2.1. Film Cleaning

For many years, the motion picture film processing industry has printed and cleaned film for theater, television and feature films. Various types of operations, including motion picture laboratories, post production facilities, studios, film preservation facilities and laboratories, regularly conduct film printing and cleaning operations. Most of the facilities in California that perform these operations are located in and around areas of Los Angeles County and are concentrated in Burbank, Hollywood and Santa Monica. Very few, if any, facilities that clean film are located in other parts of the state.

Film consists of a plastic base which supports an emulsion. Film requires cleaning periodically and the cleaning operation removes dirts such as processing sludge, lubricating oils, adhesive from tape, wax from crayons, fingerprints and lint (Fassett et. al, 1958). Historically, 1,1,1-trichloroethane (TCA) was used in virtually all operations for cleaning film. The solvent is fairly aggressive and can remove oil based contaminants as well as particulates. It is also compatible with the film base and emulsion material. In 1996, production of TCA was banned because the chemical contributes to stratospheric ozone depletion.

Over the next several years, industry tested many alternatives that could potentially replace TCA. One of the major alternatives that was adopted by the industry is perchloroethylene (PERC); the solvent had been used for years in film printing and the industry was familiar with it and knew it was compatible with and would not damage film. PERC is a carcinogen, is listed on Proposition 65 and appears on California's Toxic Air Contaminant (TAC) list and EPA's Hazardous Air Pollutant (HAP) list. Although most film cleaning was performed using PERC after the TCA production ban, some facilities later converted to a range of other alternatives including isopropyl alcohol (IPA) and various hydrocarbon solvents. Other alternatives that were adopted later are GHG solvents including HFEs and, to a small extent, HCFC-225.

2.1.1. Regulations on Film Cleaning Solvents

There are no federal regulations that directly affect the use of film cleaning solvents. Virtually all the film cleaning operations in the state are located in the jurisdiction of the South Coast Air Quality Management District (SCAQMD). SCAQMD regulates air contaminants in Los Angeles, Orange, San Bernardino and Riverside County.

In 2000, the South Coast Air Quality Management District (SCAQMD) Governing Board approved an Air Toxics Control Plan and in 2001, adopted amendments to SCAQMD Rule 1402

"Control of Toxic Air Contaminant Emissions from Existing Sources" (Rule 1402, 1994). District staff was directed to investigate the development of source specific rules for several industries, including motion picture film processing. In 2001, SCAQMD adopted Rule 1425 "Film Cleaning and Printing Operations" (Rule 1425, 2001). This rule specified a reduction in PERC emissions because of the solvent's toxicity, and film cleaning and printing operations were required to use add-on control equipment that had an overall control efficiency of 85 percent.

A technology assessment conducted as part of the rulemaking identified 50 facilities that printed or cleaned motion picture film with organic solvents in the South Coast Basin (Rogozen, 2000). Table 2-1 summarizes the estimates of the total amount of the different solvents used by the industry at the time and the average consumption per machine.

Table 2-1
Solvent Use for Film Cleaning in South Coast Basin in 2000

Solvent/Solvent Type	Annual Use	Consumption Per Machine
	(gallons/yr)	(gallons/yr)
PERC	6,070	83
TCA	2,900	126
IPA	600	37
Other VOC Solvents	2,890	NA*
HFE 7200	370	NA*

*NA is not available.
Source: Rogozen, 2000

The values of Table 2-1 show that the most widely used solvent for film cleaning in 2000 was PERC. This was before the SCAQMD adopted their regulation requiring controls for the solvent. Even though the production ban on TCA had been effective for four years, the table shows that TCA was still used extensively. The ban applied to production but did not apply to use and many companies and suppliers had supplies of the solvent for several years after the ban. The figures also illustrate that other VOC solvents were as widely used as TCA for film cleaning at the time. HFE 7200, a GHG solvent, had begun to penetrate the market although its use in 2000 was still low compared with the other solvent options. The HFE was the first GHG solvent to be used by the industry; later HCFC-225 was also adopted, but to a smaller extent. The advantage to facilities in using HFE solvents and HCFC-225 is that the solvents are exempt from VOC regulations because of their longer atmospheric lifetimes and they are not classified as TACs in California. Thus no controls are required when they are used.

Film cleaning equipment consists of an enclosed cabinet that cleans the film under negative pressure. The film is conveyed between a feed and takeup reel and is cleaned with heated solvent, often using ultrasonic energy. Ultrasonics are very effective in cleaning contaminants in blind holes and crevices and are a good choice for film. The film, before it exits the machine, is passed through a squeegee submerged in the solvent bath to remove most of the solvent adhering to the film. Finally, when the film passes out of the solvent bath, it is sprayed with a solvent jet.

Virtually all of the solvent used in the film cleaning operation was emitted in the older equipment. At the time the SCAQMD developed their regulation on PERC film cleaning and printing, the equipment used to clean film was fairly emissive, as demonstrated by the values for consumption in Table 2-1. Since then, newer equipment has been developed and it is designed to limit emissions. This was necessary, particularly for users of the GHG solvents, because they are far more expensive than the other solvents that had been used for film cleaning in the past. A picture of a newer film cleaning machine is shown in Figure 2-1.

Source: Lipsner Smith

Figure 2-1. CF3000-MKVI Film Cleaning Machine

2.1.2. Emission Inventory Baseline

IRTA contacted suppliers of the GHG solvents used in film cleaning to determine if they were willing to provide information on the amount of solvent used in the industry. The suppliers were reluctant to provide any information because it constituted proprietary market data. Because supplier data were not available, IRTA approached the problem of estimating the emission inventory baseline in a different way.

Virtually all of the facilities that perform film cleaning are located in Southern California in the jurisdiction of the SCAQMD. Film cleaning machines, regardless of the solvent used in the cleaning operations, are required to have a permit as specified in SCAQMD Rule 219 “Equipment Not Requiring a Written Permit Pursuant to Regulation II” (Rule 219, 1976). To develop the bottom up baseline inventory for the solvents used in the industry, IRTA requested the permit information for the companies with film cleaning machines from SCAQMD.

The permit information does not always provide definitive information on the identity of the solvent that is being used in each of the film cleaning machines. IRTA conducted a telephone survey of all of the facilities with permitted equipment to gather additional information on the identity of the solvent being used. In some cases, the listed contact was no longer there, was not the person in charge of the operation or the facility refused to provide information. Three of the facilities that have film cleaning machines are Title V facilities. The Title V permits aggregate the emissions across all facility operations and the identity of the solvents used in film cleaning for the Title V facilities was difficult to determine. IRTA had discussions with the SCAQMD permit engineers about additional information that could be used. IRTA also used process knowledge to help in identifying the identity of the solvents.

In cases where the solvent is routed to an oxidizer, for instance, the solvent is probably a non-halogenated VOC solvent. Non-halogenated VOC solvents are lower in price than halogenated solvents; it is nearly always more economic to destroy them and purchase new solvent than to recover them for reuse. In cases where the solvent is routed to a carbon adsorber for recovery, the solvent is likely to be PERC because of the SCAQMD regulation requiring controls. Carbon adsorbers can meet the overall control efficiency of 85 percent. Carbon adsorbers also have been commonly used to recover and reuse PERC in many other types of cleaning operations where PERC is used. PERC, because it contains halogens, is not generally routed through oxidizers because the destruction products include hydrochloric acid and chlorine. The oxidizer would have to be constructed of titanium or another resistant metal and would be very expensive. When oxidizers were specified, IRTA assumed the solvents were non-halogenated VOC solvents; when carbon adsorbers were used, IRTA assumed the solvent was PERC. When no controls were used, IRTA assumed the solvents were GHG halogenated solvents.

Based on the discussions with SCAQMD engineers regarding the Title V facilities and the permit information, telephone surveys for the other facilities and IRTA's solvent process knowledge, IRTA made estimates of the solvent identity used in all of the machines. Table 2-2 summarizes the facilities, the number of film cleaning machines at each facility and the identity of the solvent used in each machine at each facility. In some cases, the facilities have more than one film cleaning machine and some of the facilities use more than one type of solvent in their film cleaning machines. A few of the facilities still have machines that are permitted to use TCA. There is not likely to be any remaining stock of TCA but it is common practice for facilities to not surrender a permit, even when the equipment is no longer used.

The information in Table 2-2 indicates that there are four machines at one company that use HCFC-225, 18 machines at nine companies that use an unidentified HFE and three machines at three companies that use HFE-8200. Because the HFEs and HCFC-225 are GHG solvents, IRTA investigated the solvent use in these facilities further.

Table 2-3 summarizes the facilities and film cleaning machines using GHG solvents for film cleaning and provides estimates of the amount of solvent emitted from each machine. The amount of solvent used or emitted by a facility is not provided in the permit information. Many of the machines have a permit limit which is the maximum amount of solvent that can be emitted from the machine for a given period. In some cases, the permit limit was not provided in the permit information but other information required for risk calculations and other

Table 2-2 Companies and Film Cleaning Machines in South Coast Basin in 2010		
Company	Number of Film Cleaning Machines	Solvent
Fotokem Industries	4	HCFC-225
	1	PERC
	1	TCA
Technicolor Inc.	3	HFE
	9	PERC
Deluxe Laboratories	8	Other VOC
	7	HFE
Warner Brothers Studio Facilities	1	HFE
70 MM Inc.	1	PERC
The Post Group	1	HFE
Modern Videofilm Inc.	1	HFE
Golden Era Productions	1	PERC
Ascent Media	1	PERC or IPA
	1	HFE
Triage Archival Restoration Service	1	PERC
MSCL Inc., RIOT	2	IPA
MSCL Inc., Encore Hollywood	2	IPA
YCM Laboratories	1	IPA
Pro-Tek Film Vaults	1	IPA
Matchframe Video	1	IPA
Film Technology Co., Inc.	1	PERC
High Technology Video	1	HFE-8200
DKP Tomm Inc.	1	HFE-8200
4MC Company 3, Inc.	1	HFE-8200
	1	IPA
International Video Conversions	1	IPA
	1	PERC
Technicolor Creative Services	1	IPA
UCLA Film & TV Archives	1	PERC
Efilm LLC.	1	PERC
Laser Pacific Media Corp.	1	HFE
Cinetech, Ascent Media Mgmt. Srvc.	3	PERC
Cinesite, Ascent Media	1	HFE
Laser Pacific Media Corp., a Kodak Op.	1	TCA
Laser Pacific Media Corp, Pacific	2	PERC
Post Logic Studios	1	Naphtha
Technicolor Creative Services	1	HFE
Universal City Studios, LLC.	1	Naphtha
	1	HFE

purposes could be used to estimate emissions. Because many companies obtain a permit limit that is higher than they really need, the values in the table may be overestimates of the actual emissions.

Table 2-3
Facilities and Film Cleaning Machine Solvent Emissions

Company	Number of Film Cleaning Machines	Solvent	Emissions (pounds/yr)
Fotokem Industries	4	HCFC-225	710
Technicolor Inc.	3	HFE	2,605
Deluxe Laboratories	7	HFE	2,605
Warner Brothers Studio Facilities	1	HFE	4,335
The Post Group	1	HFE	2,842
Modern Videofilm Inc.	1	HFE	725
Ascent Media	1	HFE	8,694
High Technology Video	1	HFE-8200	358
DKP Tomm Inc.	1	HFE-8200	358
4MC Company 3, Inc.	1	HFE-8200	4,302
Laser Pacific Media Corp.	1	HFE	3,536
Cinesite, Ascent Media	1	HFE	2,842
Technicolor Creative Services	1	HFE	2,842
Universal City Studios, LLC.	1	HFE	427

The unspecified HFE in Table 2-3 is either HFE-7200 or HFE-8200. According to 3M, the manufacturer and supplier of the HFEs, these two HFEs, although they have a different designation, are the same chemical. MSDSs for HFE-7200 and HFE-8200 are shown in Appendix A. They are a mixture of two isomers with a GWP of 55. An MSDS for HCFC-225 is also shown in Appendix A. The HCFC is also a mixture of two isomers, HCFC-225ca and HCFC-225b. The GWP of HCFC-225 is 370.

Using a GWP for HCFC-225 of 370 and assuming each of the four machines using the chemical emits 710 pounds per year as indicated in Table 2-3, the baseline emissions of HCFC-225 are 2,840 pounds per year or 477 metric tons per year of carbon dioxide equivalent. Emissions of the HFE from the facilities listed in Table 2-3 amount to 57,311 pounds per year. Using a GWP of 55 for HFE-7200/8200, baseline emissions for the 21 machines using the chemical amount to 1,430 metric tons per year of carbon dioxide equivalent. The total baseline emissions are 1,907 metric tons per year of carbon dioxide equivalent emissions. This is about 0.002 million metric tons of carbon dioxide equivalent. Table 2-4 summarizes the 2010 baseline emissions of the two solvents and the carbon dioxide equivalent emissions for this industry.

Table 2-4 Baseline GHG Solvent Emissions from Film Cleaning Operations—2010			
Solvent	Global Warming Potential (GWP)	Annual Emissions (pounds)	Emissions (metric tons CO2e/yr)
HCFC-225	370	2,840	477
HFEs	55	57,311	1,430
Total			1,907

2.1.3. Business as Usual (BAU) Emission Projections

In the last several years, there has been a strong movement in the movie industry to digital recording. Instead of recording to film, as has been the practice historically, digital cameras are used and the recording is captured on a digital medium like hard drives or other digital recording devices. At this stage, virtually all editing and special effects are composed on computers and no splicing of film is needed. Currently, there is a movement to 3D; all 3D cameras are digital and there are no prints.

IRTA contacted industry sources familiar with the trends in the industry over the next 10 years. Knowledgeable industry sources estimate that, by 2020, the use of film and the need for film cleaning will be reduced by about 90 percent. At that stage, repositories of original negative, rare or newly discovered film will be the only facilities that may need a cleaning capability. The film will be archived and stored and there will be very little need for cleaning.

The other issue that will affect the use of the GHGs for film cleaning is that Section 605 of the Clean Air Act prohibits U.S. production and importation of all HCFCs for solvent uses by 2015 (CAAA, 1990). One of the companies cleaning film has four machines using HCFC-225. Prior to the 2015 production phaseout, the company will probably begin looking for alternatives. There may still be a supply of HCFC-225 so it is likely the company can continue using the solvent for a few additional years.

Taking the two trends into account, IRTA assumed that, in 2020, emissions of the GHGs used in film cleaning will decline by 90 percent. The rate of the decline was assumed to be uniform over the period. IRTA assumed that all use of HCFC-225 for film cleaning will stop at the end of 2017. To be conservative, IRTA assumed that the HCFC-225 will be replaced by HFE-8200 and that the emissions of HCFC-225 and HFE-8200 in a given machine are the same. On this basis, Table 2-5 shows the BAU projected emissions for 2020 and compares the projections with the baseline emissions shown in Table 2-4.

The values of Table 2-5 verify that there will be a significant decline in emissions of GHG solvents in film cleaning operations over the decade. As described in the cost analysis below, there is no need to continue the use of GHG solvents in this industry because there are viable alternatives that could be used for the limited cleaning that will still be necessary in 2020.

Table 2-5 Baseline and BAU Projections of GHG Solvent Emissions from Film Cleaning Operations				
	2010		2020	
	lb/yr	metric tons of CO2e/yr	lb/yr	metric tons of CO2e/yr
HCFC-225	2,840	477	-	-
HFE 7200/8200	57,311	1,430	6,015	150
Total		1,907		150

2.1.4. Cost Comparison of Film Cleaning Solvents

As indicated in Table 2-2, the major solvents used in film cleaning are PERC, IPA and the GHG solvents. A few machines use the petroleum solvent, naphtha, which is referred to as “Other VOC Solvents” in Table 2-2. The GHG solvents and PERC are exempt from VOC regulations whereas IPA and naphtha are classified as VOCs. As the analysis illustrates, there will be a significant decline, estimated at 90 percent, in the need for film cleaning over the next 10 years. At that stage, some, but not all companies that clean film today, will continue the practice. To investigate the issue further, IRTA performed a cost comparison and analysis for three different film cleaning agents--HFEs, PERC and IPA--in the future.

Research Technology International (RTI) owns several companies including Lipsner Smith which sells nearly all of the film cleaning equipment used in California (Mike Ruffolo, Lipsner Smith, 7/2010). Lipsner Smith recently developed a new, low emitting machine called the LS 9220-PLC for cleaning film with HFE. The machine heats the solvent to about 100 degrees F, cleans the film in a bath with ultrasonics, has a refrigerated freeboard chiller and has a self-contained distillation system. The equipment supplier estimates that the machine cleans 100,000 feet of film per gallon of solvent consumed. The cost of the machine is $89,500. Lipsner Smith recommends that any HFE user that needs a new machine purchase this model rather than an older version that could also use HFE. The new machine has better emission controls and will minimize solvent use for the user. A picture of the machine is shown in Figure 2-2.

Source: Lipsner Smith

Figure 2-2. LS9220-PLC Film Cleaning Machine

The company has another film cleaning machine, the CF 8200P, which is designed for use with PERC. According to the supplier, the machine can be easily and inexpensively modified to operate with HFE which Lipsner Smith considers the environmentally preferred solvent. This equipment also cleans ultrasonically, has a refrigerated freeboard chiller and has a distillation system. The supplier estimates this machine cleans 60,000 feet of film per gallon of PERC used. The cost of the machine is $90,750. A picture of this machine is shown in Figure 2-3.

Source: Lipsner Smith

Figure 2-3. CF8200P Film Cleaning Machine

Lipsner Smith also sells a machine for use with IPA called the Excel 2000. In this machine, the film first passes through molded polymer particulate transfer rollers to remove dirt. The film then is cleaned with eight softnap rotary buffers wetted with IPA. Unlike the machines designed for use with HFE or PERC, the film is not immersed in the liquid, no ultrasonic cleaning is used and there is no refrigerated freeboard chiller or still. The supplier estimates this machine cleans 30,000 feet of film per gallon of IPA used. The cost of the machine is $55,000. A picture of this machine is shown in Figure 2-4.

Source: Lipsner Smith

Figure 2-4. Excel 2000 Film Cleaning Machine

For the cost analysis, the amount of solvent used in the HFE machine for a typical facility is assumed to be 100 gallons per year. This value is slightly less than the average solvent use of 129 gallons per year for the facilities using GHG solvents listed in Table 2-3. Over the next several years, the solvent use will decline because of the movement to digital technology. A value of 100 gallons per year is likely to be representative for a user over the next 10 year period. More PERC would be required for the typical user, about 166 gallons per year to clean the same amount of film based on the machine consumption values. Even more IPA would be required, about 333 gallons per year, to clean the same amount of film, again based on the machine consumption values.

For film cleaning machine purchases, IRTA assumed that the cost of capital is four percent and that the useful life of the machine is 10 years for the cost analysis. On this basis, the annualized capital cost for the HFE, PERC and IPA machines is $9,308, $9,438 and $5,720 respectively.

Two scenarios were considered for the PERC equipment. In addition to film cleaning, the post production industry also prints film and the solvent used in the printing operation is always PERC. The SCAQMD regulation requires control equipment for both film cleaning and film printing equipment using PERC. Some of the facilities that have film cleaning equipment, perhaps as many as 25 percent of the companies, also do film printing. These companies have already purchased and are operating control equipment for the film printing machines and the PERC used in their film cleaning equipment could also be routed to the control equipment. The first scenario would apply to companies which already have control equipment; in this event, they would not have to purchase control equipment since they already have it. The second scenario would apply to companies that have to purchase control equipment to use PERC in a film cleaning machine.

The commonly used control equipment for PERC is carbon adsorption. PERC is routed to a carbon adsorber through a duct in the top of the film cleaning machine. The PERC is adsorbed to the carbon. In some cases, where the PERC stream is very large, it would be cost effective to have an adsorption/desorption system. When the carbon is full, steam is traditionally used to drive the PERC off the carbon, the PERC is condensed, separated from the water and reused in the process. In cases where the PERC stream is smaller, an adsorption-only system would be used. The PERC is adsorbed to the carbon bed. When the bed is full, the carbon is removed and fresh carbon is placed in the bed. The used carbon is shipped off-site and burned.

IRTA contacted Carbon Resources, a carbon supplier, to obtain an estimate for the cost of a carbon adsorption system for a PERC film cleaning machine (Walsh, 7/ 2010). According to Lipsner Smith, the flow rate in the vent at the top of the PERC film cleaning machine averages about 100 cubic feet per minute. Using this value, together with the usage of 166 gallons per year and the isotherm for PERC, Carbon Resources recommends an adsorption-only system which would consist of two Gaurdian V-1000 units in series and a blower for vacuum operation. This system would include all necessary piping, valves, gauges and a simple on/off control panel. A picture of a typical system of this type is shown in Figure 2-5. The cost of a system would be between $12,000 and $15,000, including delivery and set up. Again, assuming a cost of capital of four percent and a 10 year life for the equipment, the annualized cost for the carbon adsorption system using the higher figure of $15,000 to be conservative, would amount to $1,560.

Source: Carbon Resources

Figure 2-5. Typical Carbon Adsorption System for Film Cleaning Machine

In addition to the capital costs of the equipment, a typical facility using film cleaning equipment would also have operating costs. IRTA assumed the operating costs, like electricity use and filter replacement, would be similar across the different types of machines. One operating cost that would be substantially different is that the PERC carbon adsorption system would require replacement and disposal of the spent carbon. Based on the systems quoted by Carbon Resources, the company estimates this cost at between $1,250 and $2,000 annually based on whether or not the spent carbon is classified as hazardous waste. Since PERC is a listed waste in the Resource Recovery and Control Act, it would be classified as hazardous waste by definition. IRTA used the higher value of $2,000 per year for the regeneration/disposal cost.

Another operating cost that would vary is the cost of purchasing the solvent. According to a chemical supplier who supplies solvent to this industry, the companies generally purchase their solvents in drum quantities (Isaacs, 7/2010). The HFE is very expensive, about $15,000 per drum. The price of a drum of PERC is about $900 per drum and the price of IPA is $450 per drum. Assuming a drum contains 55 gallons, the cost of using 100 gallons of HFE annually is $27,273. The cost of using 166 gallons of PERC is $2,716 annually and the cost of using 333 gallons of IPA is $2,725 per year.

As mentioned above, the HFE and PERC machines have a distillation system which recovers the liquid solvent for reuse. The still bottom from the distillation process requires disposal as hazardous waste. For the HFE, IRTA assumed that 30 percent of the HFE used, or 30 gallons, would be disposed of as still bottom. Solids like still bottoms are incinerated at a cost of about $1 per pound. Assuming a solvent density of 12 pounds per gallon, the cost of disposal of the HFE still bottom would amount to $360 per year. For the PERC still bottom, about 50 gallons per year would require disposal. Using 13.6 pounds per gallon for the PERC density, the cost of disposal for the PERC would be $677 annually. The IPA cleaning system does not have distillation so all of the IPA is assumed to evaporate.

The cost of using each of the three solvents is summarized in Table 2-6. The table shows the annualized cost of purchasing the cleaning equipment and the control equipment. It also shows the carbon disposal cost for the PERC system, the annual cost of solvent purchases and the still bottom disposal costs which do not apply to the IPA system. If the company already had a control system for PERC because it was needed for film printing operations, the company would not have to purchase control equipment (called PERC With Control in the table). The company would still have to dispose of the spent carbon from the film cleaning operation, however, and the annualized cost of using the PERC system would be $14,831 instead of $16,391.

Table 2-6
Annualized Cost Comparison for Film Cleaning Solvents

	HFE	PERC Without Control	PERC With Control	IPA
Cleaning Equipment Cost	$9,308	$9,438	$9,438	$5,720
Control Equipment Cost	-	$1,560		-
Carbon Disposal Cost	-	$2,000	$2,000	-
Solvent Cost	$27,273	$2,716	$2,716	$2,725
Still Bottom Disposal Cost	$360	$677	$677	-
Total Annualized Cost	$36,941	$16,391	$14,831	$8,445

The figures of Table 2-6 show that the lowest cost option is to use IPA for film cleaning. The disadvantage of the IPA system, however, is that it does not clean as well as the other systems because the film is not immersed in the solvent and it is not cleaned with ultrasonic energy. On the other hand, the HFE is an extremely gentle solvent and is not effective in removing many types of contaminants so it would not be as effective a cleaner as PERC in an immersion system. The cost of using the PERC system, even with the requirement that the PERC be controlled, is less than half the cost of using the HFE system.

2.1.5. Advantages and Disadvantages of Alternative Film Cleaning Methods

The solvents used in film cleaning pose a variety of health and environmental problems. The HFE is a GHG but it is low in toxicity. IPA is also relatively low in toxicity but it is a VOC. It is likely that a company using IPA in a film cleaning machine would use less than the SCAQMD threshold for required offsets. The typical usage assumed in the cost analysis above would be well below this threshold. PERC is classified as a carcinogen. It is on EPA's HAP list, California's TAC list and is listed on Proposition 65. Other industries using the chemical have been heavily regulated and SCAQMD has required a high degree of control for the PERC emissions in this industry. Workers in the movie industry will be exposed to PERC while filling the machine, during the film cleaning operations and when removing the still bottom after distillation.

The solvents also vary as far as performance and cost are concerned. As mentioned above, HFE is a very non-aggressive cleaning solvent and will not remove heavy contamination. IPA is a better cleaner for polar contaminants like fingerprints but also cannot remove oil based contaminants very effectively. PERC is an aggressive cleaner and can remove heavy oil based contaminants. All three solvents are safe for use on the film base. The cost of the HFE is very high; the cost of the other solvents is much lower.

Table 2-5 shows that the need for solvent cleaning will decline substantially by 2020. Use of the HFE at that stage will amount to only 150 metric tons of carbon dioxide equivalent per year based on about 2.7 metric tons of HFE use. Because PERC is a carcinogen, it poses a risk to workers and community members surrounding the facilities where it is used so it is not a good alternative to the HFE. IPA, on the other hand, is relatively low in toxicity. Its major disadvantage is that it is a VOC. It is a viable alternative to the HFE, however. If it were to completely replace the HFE, its use in 2020 would increase by about 9.1 metric tons or about 0.025 metric tons per day.

<u>2.1.6. Alternative 2020 Emission Projection Scenarios</u>

Two alternative projection scenarios were analyzed for film cleaning. The first scenario involves replacing the existing equipment using HFEs with the more conservative equipment available from Lipsner Smith today. The second scenario involves substituting the not-in-kind alternatives, PERC and IPA, for the HFE.

<u>2.1.6.1. Adoption of lower emitting equipment</u>

Under this scenario, the companies using HFEs would replace their machines with lower emitting equipment. The new equipment, the LS9220-PLC, as described above, is priced at $89,500. The annualized cost of this equipment was determined above, assuming a 10 year useful life and a four percent cost of capital. This amounts to an annualized machine cost of $9,308. Most companies using HFEs purchased the older equipment model which has a higher consumption rate for the solvent. The equipment supplier (Ruffolo, 10/2010) indicates the old machine cleans about 60,000 feet of film per gallon of solvent used; the cleaning rate is considerably higher, at 100,000 feet per gallon of solvent, with the new machine. For the analysis conducted earlier, it was assumed that the typical HFE user used about 100 gallons of solvent per year in the new equipment. On this basis, the HFE consumption in the old equipment would amount to 167 gallons based on the consumption figures. Again, assuming the cost of a 55 gallon drum of HFE is $15,000, solvent purchases would amount to $27,273 annually with the new equipment and $45,545 per year with the old equipment. For purposes of analysis, it was assumed that the cost of still bottom disposal with the two machines is the same.

Table 2-7 presents the annualized cost comparison for the new and old equipment. The newer less emissive equipment is the LS 9220-PLC and the older equipment is the CF 9200. The companies with older equipment do not have a capital cost for the equipment but they do have higher solvent use.

Table 2-7 Annualized Cost Comparison for HFE With Newer and Older Equipment		
	LS 9220-PLC (New Equipment)	CF 9200 (Older Equipment)
Equipment Cost	$9,308	-
Solvent Cost	$27,273	$45,545
Total Annualized Cost	$36,941	$45,545

The values of Table 2-7 show that the cost of using the newer equipment is lower than the cost of continuing to use the older equipment, even though the new equipment is expensive. The reduction in solvent purchases more than offsets the capital cost of the machine. Lipsner Smith indicates that, in some cases, where users fully optimize use of the newer machine, the consumption can be higher than 100,000 feet per gallon and may be as high as 130,000 feet per gallon.

In the baseline emissions estimate presented earlier, emissions of HFE 7200/8200 were projected to be 6,015 pounds per year or 150 metric tons of carbon dioxide equivalent per year in 2020. This is a reduction of 90 percent over the ten year period. If all HFE users purchased the new more efficient machines, emissions would be reduced from 6,015 pounds per year to 3,602 pounds per year, a reduction of 40 percent. Emissions would be reduced from 150 to 90 metric tons of carbon dioxide equivalent per year.

2.1.6.2.. Substitution of PERC or IPA for HFE

For the BAU emission projection scenario, the film cleaning emissions of HFE were estimated to decline to 6,015 pounds per year or 150 metric tons of carbon dioxide equivalent in 2020. Under this scenario, if PERC or IPA were to substitute completely for the HFE, there would be a reduction in HFE emissions of 6,015 pounds per year or 150 metric tons of carbon dioxide equivalent. If IPA were the alternative, there would be an increase in IPA emissions of 9.1 tons per year or 0.025 metric tons per day. The consequence, if IPA were used, would be a small increase in VOC emissions. If PERC were the alternative, the increase in PERC emissions would amount to 11,316 pounds or about 5.1 metric tons per year. On a daily basis, the PERC emissions for the industry would be 0.014 metric tons. The consequence, if PERC were used, would be an increase in emissions and risk posed by a carcinogen.

2.1.7. Summary of BAU and Alternative Projection Scenarios

Table 2-8 presents and summarizes the emissions of the three different projection scenarios. The BAU scenario assumes a decline in solvent use of 90 percent and a conversion from HCFC-225 to the HFEs by 2020. The first alternative scenario is based on replacing existing HFE equipment with newer HFE equipment that minimizes emissions. The second alternative scenario is based on the industry converting away from HFEs to PERC or IPA.

Table 2-8 Comparison of BAU and Alternative Emission Projection Scenarios		
Scenario	Emissions (metric tons/yr)	Emissions (metric tons of CO2e/yr)
BAU	2.7	150
Purchase Better Equipment	1.6	90
Substitute PERC for HFEs	5.1	-
Substitute IPA for HFEs	9.1	-

2.2. Vapor Degreasing

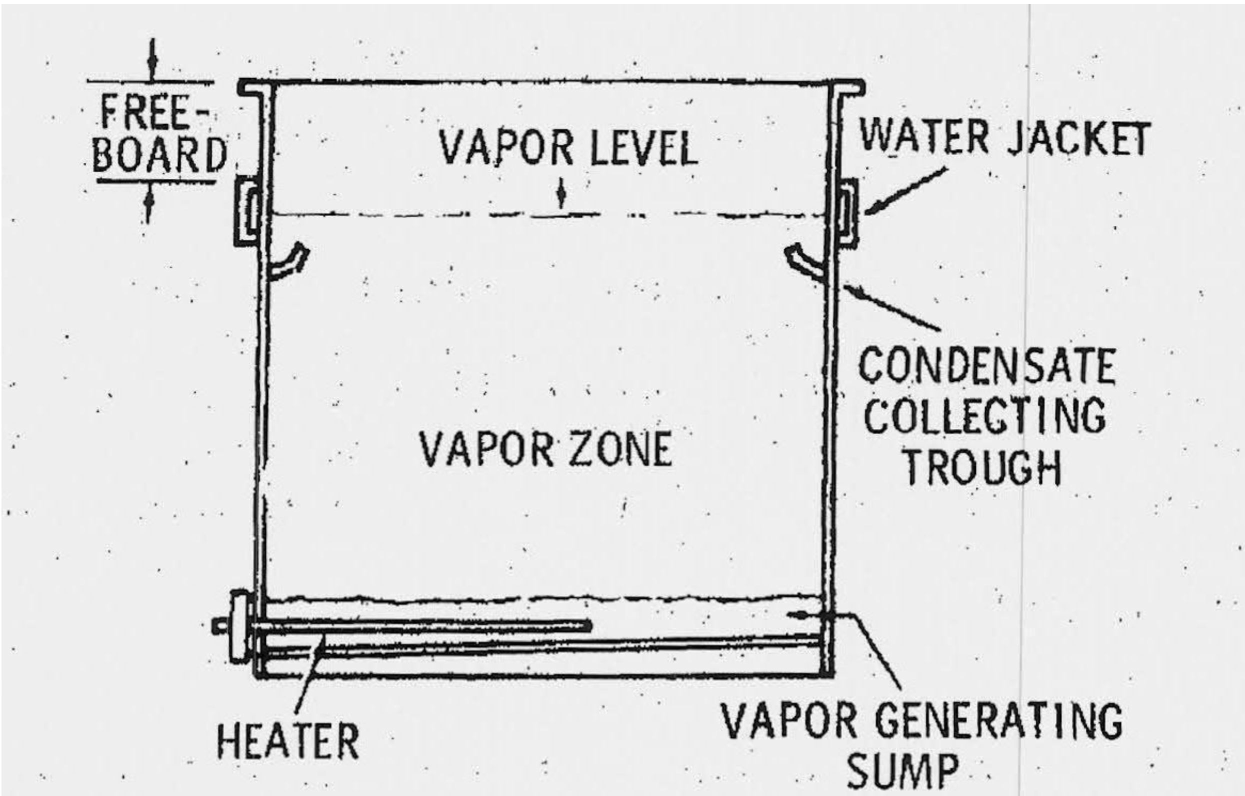
For many years, companies have used vapor degreasers to clean metal and plastic parts in fabrication and repair and maintenance cleaning operations. In general, the types of operations where vapor degreasers are most widely used have been higher technology industries such as metal fabrication, electronics and precision cleaning of various kinds.

In the 1960s, halogenated solvents began to be used extensively for cleaning purposes. These solvents included trichloroethylene (TCE), PERC, methylene chloride (METH) and TCA. Vapor degreasers were developed to capitalize on the physical properties of halogenated solvents. These solvents generally do not have flash points and they can be heated to their boiling point for more effective cleaning.

A schematic of a typical open-top vapor degreaser is shown in Figure 2-6. The simplest type of vapor degreaser is a large stainless steel tank with a heater that heats the solvent to its boiling point. The degreaser has a set of cooling coils above the liquid zone that condenses the solvent vapors back into the tank. The parts are lowered into the vapor zone, the solvent vapor condenses on the cooler parts and carries the contaminants into the liquid solvent below. Some vapor degreasers also have a spray wand which can be used to spray the parts in the vapor zone. Sometimes the parts are lowered into the liquid solvent as well as the vapor zone. The advantage of cleaning in the vapor zone is that the liquid solvent contains the contaminants and the solvent vapor is comparatively clean.

The soils build up in the liquid solvent and eventually the solvent becomes too contaminated for further use. At that stage, the solvent is distilled in an on-site distillation system or is sent off-site where it is distilled by a recycling firm. The distillation procedure separates the pure solvent from the higher boiling contaminants which may be oils, greases or flux. The contaminants remain in the still bottom and it is disposed of as hazardous waste.

Solvent emissions occur from the top of the vapor degreaser during operation and solvent is also dragged out on the parts that are removed from the degreaser. Many degreasers, particularly those used today with more expensive materials like the GHG solvents, are much more sophisticated and they have features like refrigerated freeboard chillers, a much higher freeboard height to better contain the solvent and automated handling systems to substantially reduce dragout. These features are designed to minimize emissions.



Source: Hoogheem et. all., 1979

Figure 2-6. Typical Open Top Vapor Degreaser

Prior to 1996, the most widely used halogenated solvent in vapor degreasers in California was TCA. The solvent is exempt from VOC regulations whereas, at the time, TCE and PERC were regulated as VOCs. METH was also used in some processes; like TCA, METH was exempt but it is a much more aggressive solvent so it was not compatible with as many materials as TCA. In the 1970s, evidence emerged that TCE, PERC and METH are carcinogens and TCA was even more widely adopted since it was not classified as a VOC and it was considered to be lower in toxicity. CFC-113, also exempt from VOC regulations, was extensively used in vapor degreasing for electronics and precision cleaning, but it was never used as widely as TCA because of its higher cost.

In 1996, production of TCA and CFC-113 was banned because the solvents contribute to stratospheric ozone depletion. Many users continued to use the solvents as long as a supply was still available. Over the next several years, the remaining TCA and CFC-113 were exhausted and companies had to find, test and implement alternatives. Most companies adopted water-based cleaning processes as alternatives. Some companies converted to PERC, which was by then classified as VOC exempt, but toxics regulations prevented widespread conversion to the solvent.

New solvents that had lower or no ozone depletion potential were developed as suppliers saw a market opportunity. These included HCFCs, a brominated solvent called n-propyl bromide (nPB), HFCs and HFEs. Many companies began using HCFC-141b in vapor degreasing as a replacement for TCA; like TCA, it was not classified as a VOC and it was low in toxicity. The solvent had a fairly high ozone depletion potential (about the same as that of TCA) and its use was banned in many cleaning applications in 2003. Some companies began using HCFC-225 which was similar in cleaning properties to CFC-113. The HCFC is not classified as a VOC. It has a fairly low ozone depletion potential but production is scheduled to be banned in 2015. nPB was marketed as a replacement for TCA in vapor degreasing applications and a number of companies adopted it. The solvent is classified as a VOC and has since been found to be a reproductive toxin and to cause nerve damage (HESIS, 2003).

HFC-4310 and a few HFEs were marketed as alternatives to the ozone depleting solvents. Because they are gentle cleaners, however, they were generally used in combinations with 1,2-trans dichloroethylene (DCE), a chlorinated solvent with a flash point. The combinations do not have flash points so the solvents can be used in vapor degreasers. DCE is classified as a VOC whereas HFC-4310 and the HFEs are exempt from VOC regulations.

2.2.1. Cleaning Characteristics of Vapor Degreasing Solvents

The GHG solvents used in vapor degreasing today include HCFC-225, HFC-4310 and the HFEs. Other solvents used to some extent in California include nPB and the traditional chlorinated solvents, PERC and TCE. TCE, PERC and nPB are aggressive solvents and they are used to clean oil, grease or buffing compound from parts. The components that make these solvents aggressive cleaners are the chlorine and the bromine they contain. nPB is also used, to some extent, for precision cleaning but its uses are somewhat limited in this arena because it is aggressive. This means that it can be incompatible with certain types of plastic which are often used in the fabrication of precision parts.

HCFC-225 is the most aggressive of the global warming solvents; it is aggressive because it contains chlorine; even so, it is much less aggressive than the chlorinated solvents or nPB. HFC-4310 and the HFEs are very non-aggressive since they contain no chlorine or bromine. They are virtually always combined with DCE and other solvents, like alcohols, that increase their cleaning capability. The cleaning capability of HCFC-225 is also sometimes enhanced by the addition of DCE and/or alcohols. HFC-4310 and the HFEs alone are sometimes used to rinse parts after the contaminants have been cleaned with another solvent and they enhance drying. The GHG solvents have very high vapor pressures so they evaporate quickly, leaving a dry part.

The GHG solvents are nearly always used for precision cleaning of higher value parts rather than for heavy cleaning tasks. This follows from the fact that they are non-aggressive cleaners and they are also much more expensive than PERC, TCE and nPB.

2.2.2. Regulations on Vapor Degreasing Solvents

There are two types of regulations that affect the pattern of solvent use in California. First, EPA regulations on ozone depleting and global warming solvents have affected the choice of solvents. Second, the local air districts in California regulate air contaminants from stationary sources. None of the air districts regulates global warming solvents per se. They do have regulations, however, that affect a company's choice of solvent for vapor degreasing. Each of these types of regulations is described below.

2.2.2.1. EPA Regulations

In 1994, EPA published the first major regulation that defined certain alternatives to ozone depleting substances as acceptable, acceptable with certain limits or unacceptable (EPA, 1994). The Significant New Alternatives Policy (SNAP) program passed several additional regulations in the years thereafter that focused on other alternatives. EPA designated certain PFCs as acceptable in electronics cleaning and precision cleaning as alternatives to CFC-113 and TCA with certain limitations (EPA, 1994). The PFCs were acceptable for high performance, precision-engineered applications "only where reasonable efforts have been made to ascertain that other alternatives are not technically feasible due to performance or safety requirements." At that time, EPA was concerned about the high global warming potential of the PFCs and wanted users to adopt other alternatives where possible. EPA did not deem the PFCs acceptable in metals cleaning. The three categories, metals cleaning, electronics cleaning and precision cleaning, are the only categories of cleaning covered by EPA. EPA did not define other categories where PFCs might be used and remained silent on the acceptability of their use. An example of a category not considered by EPA is disk lubing which is discussed later in the next section. Some companies were using PFCs for this application at the time and they could continue doing so if they desired.

EPA took two other actions on alternatives in later reviews. First, the agency deemed HCFC-141b unacceptable for non-aerosol cleaning purposes; EPA later extended the phaseout date to January 1, 1997. Because of HCFC-141b's high ODP, its production was phased out on January 1, 2003. Second, under Section 605 of the Clean Air Act, EPA prohibits U.S. production and importation of all HCFCs for solvent uses by 2015. This prohibition affects HCFC-225. Because it is a production/importation ban, as long as stockpiles of HCFC-225 remain, the solvent will continue to be used.

2.2.2.2. Local Air District Regulations

The SCAQMD regulates roughly half the stationary sources in the state. SCAQMD Rule 1122 "Solvent Degreasers" regulates the solvents used in vapor degreasers (Rule 1122, 1979). In 1997, the District established a 25 gram per liter VOC limit for solvents used in open top vapor degreasers but included several exemptions. Over the next several years, the exemptions were tightened and are fairly narrow today. The exemptions apply only to very small vapor degreasers with an open top surface area less than 1.0 square foot or with a capacity of less than two gallons that are used for certain types of cleaning activities. Companies in the South Coast Basin could continue to use higher VOC content solvents but they were required to use them in airless/airtight degreasers rather than the open top degreasers that are widely used. These airless/airtight degreasers are much more expensive than open top degreasers.

At the time the SCAQMD regulation was amended, many companies in the Basin were using nPB and, since the solvent is a VOC, these companies had to convert away from the solvent. Also at the time, most of the HCFC-225, which is a gentle cleaner, was combined with VOC solvents and the VOC content of the blends exceeded the 25 gram per liter limit. Some of the companies using the solvent converted away from HCFC-225 blends. The suppliers were able to reformulate the HCFC-225 blends to the 25 gram per liter limit eventually and these blends were effective in some of the applications. Today, some companies are using HCFC-225 alone or in a 25 gram per liter blend, usually with alcohol. HCFC-4310 and the HFEs were rarely used alone prior to 1997. Again, the solvents are very non-aggressive and require substantial quantities of DCE to perform effectively. After the SCAQMD 1997 lower VOC limit was adopted, nearly all companies in the South Coast Basin converted away from these solvents. A few companies, who used the solvents in the narrow exemptions or in airless/airtight degreasers, continued to use the blends.

The SCAQMD is the only air district that has limits on the VOC content of vapor degreasing solvents. Other air districts in the state do not have such regulations so a wider variety of solvents are used in the rest of the state. nPB is more widely used in other parts of California because it is a much less expensive solvent than HCFC-225, HFC-4310 and the HFEs and it is also much more aggressive. The higher VOC content blends of HCFC-225, HFC-4310 and the HFEs are also used to some extent in the jurisdiction of other California air districts.

2.2.3. Emission Inventory Baseline

The suppliers of vapor degreasing solvents were reluctant to share comprehensive information on solvent use because of competitive market concerns. IRTA had to use a different approach to develop a baseline inventory of the solvent emissions. Vapor degreasers generally require permits from local air districts. To gather data for the bottom up inventory estimates, IRTA requested the list of vapor degreaser permits from major air districts in the state where virtually all of the industrial activity is likely to occur. It is in these air districts where vapor degreasers are likely to be operated. In particular, since the GHG solvents are relatively expensive compared with other vapor degreasing solvents, the focus was on air districts where there is high technology industrial activity. The air districts targeted for the data collection included SCAQMD, the Bay Area Air Quality Management District (Bay Area AQMD), the Sacramento Metropolitan Air Quality Management District (Sacramento Metropolitan AQMD), the San Diego County Air Pollution Control District (San Diego County APCD) and the Ventura County Air Pollution Control District (Ventura County APCD).

The lists of permitted vapor degreasers often do not identify the types of solvents used so IRTA requested additional information from the air districts on the permit conditions. In some cases, even this information did not identify the solvent used. For instance, some air districts group certain solvents into one category so all that can be determined is that the company with the vapor degreaser is using one of a number of solvents. In other cases, companies obtain vapor degreaser permits which allow them to use more than one solvent. To be conservative, in these cases, if one of the options was a GHG chemical and the other was not, IRTA assumed the GHG chemical was used. In certain instances, IRTA had to use judgment and process knowledge of how solvents are used to decide what solvent is used in a particular vapor degreaser. IRTA then eliminated the vapor degreasers using solvents that are not GHG chemicals from further consideration.

In virtually all cases, there is no information on the actual usage and emissions of the solvents from the vapor degreasers. IRTA used the information from the air districts on the permit limits placed on the vapor degreasers to estimate the annual emissions. The permit limits are generally given in gallons per year. In some cases, the solvent is a blend of a GHG solvent and a non-GHG solvent. For instance, as described earlier, HFC-4310 and the HFEs are commonly combined with VOC solvents to achieve greater cleaning aggression. Thus, a large fraction of the blend would not be a GHG solvent. In these cases, IRTA used only the amount of the GHG solvent to determine the baseline emissions.

To augment the air district information on permits, IRTA also had conversations with some of the suppliers of chemicals and equipment. In some cases, the suppliers were helpful in identifying the type of solvent used. An issue that arose during the analysis is that many companies in the South Coast Basin are under the impression that they do not need a permit for a vapor degreaser if they are using it with a solvent that is exempt from VOC regulations. This is not the case; permits are required for vapor degreasers even when the solvent used is exempt. IRTA encountered one company using a large amount of a GHG solvent that did not have a permit. This indicates that there may be other companies using GHG solvents in vapor degreasers without a permit. They would not be included in the analysis.

2.2.3.1. Sacramento Metropolitan AQMD

There are apparently no vapor degreasers in the jurisdiction of the Sacramento Metropolitan AQMD.

2.2.3.2. Ventura County APCD

In the jurisdiction of the Ventura County APCD, there are six companies using seven vapor degreasers. Five of the vapor degreasers use nPB, one uses PERC and one uses TCE. There are no vapor degreasers using GHG solvents.

2.2.3.3. San Diego County APCD

In the jurisdiction of the San Diego County APCD, there are 18 companies using 28 vapor degreasers. Eight of the companies are using nine vapor degreasers that rely upon GHG solvents. The permits in this air district, in many cases, do list the solvent and even the tradename of the solvent that is used. Table 2-9 shows the vapor degreasers in the jurisdiction of the San Diego County APCD that use GHG solvents. It lists the company name, the tradename of the solvent used in the vapor degreaser and the type of solvent. In one case, AEM, Inc., the air district was unable to locate the permit file so it is not possible to determine what solvent the company is using. Although the company is listed in Table 2-9, IRTA did not consider the vapor degreaser used by the company further.

Table 2-9 Vapor Degreasers Using GHG Solvents in San Diego County APCD Jurisdiction		
Company	Solvent Name	Solvent Type
General Atomics	Rhotron 225TM	HCFC-225
Deutsch ECD	HFE-71DE	HFE
BAE Systems	Vertrel SMT	HCFC-4310
Teledyne KW Microwave	Rhotron 225TM	HCFC-225
Remec Broadband Wireless	Rhotron 225TM	HCFC-225
	Rhotron 225TM	HCFC-225
Ectron Corp.	HFE-72DE or Vertrel SMT	HFE or HFC-4310
Interface Displays & Controls Inc.	Rhotron 225TM	HCFC-225
AEM Inc.	NA*	NA*
GDE Systems, Inc.	Vertrel SMT	HFC-4310

*NA is not available

As discussed earlier, the SCAQMD has a regulation that restricts the VOC content of solvents used in vapor degreasers. The San Diego County APCD does not have such a regulation so companies can use GHG solvents in blends with VOC solvents. Virtually all of the solvents in Table 2-9 are blends with a fairly high content of the VOC solvent. An MSDS for Rhotron 225TM is shown in Appendix A. It is a blend of HCFC-225 with DCE and methanol as well as a stabilizer, nitromethane. MSDSs for HFE-71DE (called HFE-71D in the air district files) and HFE-72DE are shown in Appendix A. These two materials are blends of HFEs and DCE. Finally, an MSDS for Vertrel SMT is shown in Appendix A. It is a blend of HFC-4310 with DCE and methanol.

Table 2-10 shows the permit limit or the requested limit for the daily solvent emissions in pounds or gallons for the GHG solvents used in San Diego County APCD. It also shows the emissions of GHG solvents in pounds per year. As the MSDSs for the formulations used by the companies indicate, the solvents contain several ingredients and only some of them are GHG solvents. For Ectron Corp., the company is allowed to use either HFE-72DE or Vertrel SMT. Because HFC-4310, the GHG solvent in Vertrel, has a higher GWP than the HFEs, it was assumed the company was using Vertrel SMT to be conservative. As mentioned above, AEM Inc.'s solvent use was excluded from Table 2-10 because the air district could not locate the company's file.

Table 2-11 shows the companies emitting GHG solvents, the identity of the solvent and the annual emissions of GHG solvents in metric tons of carbon dioxide equivalent. A GWP of 370 was used for HCFC-225, a GWP of 55 was used for the HFEs and a GWP of 1,500 was used for HFC-4310 in the calculations. The values indicate that 5.3 thousand metric tons of carbon dioxide equivalent GHG solvents are emitted from companies in the San Diego area each year.

Table 2-10 Estimated Emissions of GHG Solvents in San Diego County APCD Jurisdiction		
Company	Permit or Requested Solvent Emission Limit	GHG Solvent Emissions (pounds/yr)
General Atomics	10 pounds/day	3,322
Deutsch ECD	9.15 pounds/day	1,449
BAE Systems	7.6 pounds/day	1,449
Teledyne KW Microwave	0.3 pounds/day	100
Remec Broadband Wireless	0.5 gal/day	1,825
	0.5 gal/day	1,825
Ectron Corp.	1.5 pounds/day	3,246
Interface Displays & Controls Inc.	10 pounds/day	3,322
GDE Systems Inc.	0.25 gal/day	541

Table 2-11 Estimated Weighted Emissions of GHG Solvents in San Diego County APCD Jurisdiction		
Company	GHG Solvent	GWP Weighted Emissions (metric tons CO2e/year)
General Atomics	Rhotron 225TM	558
Deutsch ECD	HFE-71D	36
BAE Systems	HFC-4310	986
Teledyne KW Microwave	Rhotron 225TM	17
Remec Broadband Wireless	Rhotron 225TM	306
	Rhotron 225TM	306
Ectron Corp.	Vertrel SMT	2,209
Interface Displays & Controls Inc.	Rhotron 225TM	558
GDE Systems Inc.	Vertrel SMT	368
Total		5,344

2.2.3.4. Bay Area AQMD

Table 2-12 summarizes the companies with vapor degreasers using GHG solvents in the jurisdiction of the Bay Area AQMD. In one case, the vapor degreaser permit was for CFC-113 and this facility was eliminated from further consideration. As discussed earlier, there is virtually no supply of CFC-113 available and companies are reluctant to surrender permits. It is likely that this company is no longer using the vapor degreaser or is using another solvent in the degreaser but is not aware that the permit requires modification. In either case, there is no way to determine the solvent the company is actually using if the vapor degreaser is still in use.

Table 2-13 shows the permit or requested limit of solvent emissions for each of the GHG solvent vapor degreasers in the Bay Area AQMD jurisdiction. The information from the Bay Area AQMD indicates the gallons per year or the pounds per day or year of “net solvent.” Beyond the name of the solvent, there is no information on the tradename of the solvent or blend that is being used. For purposes of analysis, it was assumed that the HFC-4310 blend used by each facility was Vertrel SMT which is composed of about 52 percent HFC-4310. When

Table 2-12 Vapor Degreasers Using GHG Solvents in Bay Area AQMD Jurisdiction	
Company	Solvent Type
Hitachi Global Storage Tech. Inc.	HFE, HFC-4310
	HFC-4310
Agilent Technologies	fully halogenated hydrocarbons
	HFC-4310
Teledyne Microwave	HCFC-225
	HCFC-225
Anritsu Company	HCFC-225
	HCFC-225
Rockwell Collins Display Systems	HCFC-225
Seagate Technology, LLC	perfluorocarbons
	HFC-4310
Space Systems/Loral	HCFC-225
CHA Industries	fully halogenated hydrocarbons
Coherent Inc.	HCFC-225
Giga-tronics, Inc.	HCFC-225
WD Media, Inc.	perfluorocarbons
Oclara, Inc.	HFE, nPB
JDS Uniphase	HFE
JEM America Corp.	HCFC-225
Bio-Rad Laboratories	HFC-4310, IPA
Americal Medical Systems	HCFC-225
SV Probe	HCFC-225
Highland Technology, Inc.	HCFC-225
Cobham Defense Electronic Syst.	fully halogenated hydrocarbons
	HCFC-225

the listed solvent was HFE, IRTA assumed the solvent was HFE-71DE which contains 50 percent HFE. MSDSs for each of these blends are shown in Appendix A. In a few cases, two solvents--one a GHG solvent and the other a non-GHG solvent--were used. In these instances, IRTA assumed that half of each solvent was used.

When the solvent was specified as "fully halogenated hydrocarbons," IRTA tried to obtain additional information on the identity of the solvent by calling the company representative. Agilent Technologies no longer uses either of their vapor degreasers. CHA Industries is using nPB, a non-GHG solvent, in their vapor degreaser. Cobham Defense Electronic Systems is using HCFC-225 in the vapor degreaser now and IRTA assumed the company is emitting 38 gallons per year of the solvent, the permit limit. With this information in mind, IRTA eliminated Agilent Technologies and CHA Industries from further consideration. IRTA included Cobham Defense Electronic Systems in the analysis as using HCFC-225.

Table 2-13 Estimated Weighted Emissions of GHG Solvents in Bay Area AQMD Jurisdiction		
Company	Permit or Requested Solvent Limit	GWP Weighted Emissions (metric tons CO2e/yr)
Hitachi Global Storage Tech. Inc	1.7 pounds/day HFE and	8
	1.8 pounds/day HFC-4310	224
	1.8 pounds/day	447
Teledyne Microwave	32.15 gal/yr	70
	58.8 gal/yr	128
Anritsu Company	85 gal/yr	184
	83 gal/yr	180
Rockwell Collins Display Systems	195.8 gal/yr	425
Space Systems/Loral	33.85 gal/yr	73
Coherent Inc.	115 gal/yr	249
Giga-tronics, Inc.	20 gal/yr	43
Oclara, Inc.	15 gal/yr	1
JDS Uniphase	260 gal/yr	37
JEM America Corp.	50 gal/yr	108
Bio-Rad Laboratories	25.5 gal/yr	51
Americal Medical Systems	98 gal/yr	213
SV Probe	110 gal/yr	239
Highland Technology, Inc.	12 gal/yr	26
Cobham Defense Electronic Syst.	38 gal/yr	61
	20 gal/yr	43
Total		2810

IRTA also called facility representatives at the two companies listed as using "perfluorocarbons." WD Media Inc. does not have a vapor degreaser and uses a non-fully halogenated GHG solvent as a carrier medium for disk lubing, a different application. Seagate Technology no longer has production capability in this country and is using HFC-4310 and the PFC in disk lubing operations for R&D testing purposes. The facility would not provide any more information so IRTA assumed the company is emitting it at the levels permitted. With this in mind, IRTA classified the two facilities into a new category, disk lubing, which is considered later in the next section.

The GWP weighted emissions were determined using a GWP of 370 for HCFC-225, a GWP of 55 for the HFEs and a GWP of 1,500 for HFC-4310. On this basis, the values of Table 2-13 indicate that somewhat less than three thousand metric tons of carbon dioxide equivalent GHG solvents are emitted each year in the Bay Area AQMD.

2.2.3.5. SCAQMD

Table 2-14 summarizes the companies and the GHG solvents used in the jurisdiction of the SCAQMD. Some of the companies have permits for CFC-113 and/or CFC-11. IRTA assumed, since it is unlikely there is any remaining CFC, that these companies are simply leaving their permits active (not cancelling them) but are not actually using the CFCs in the vapor degreasers. One company has a permit for a degreaser using HCFC-141b. This solvent has not been used for cleaning for several years, so that degreaser was excluded from the analysis. In some cases, the identity of the solvent is not available and these cases are indicated by NA in the table.

When companies were allowed to use more than one solvent or when there was no information on the identity of the solvent, IRTA had to make assumptions about the GHG solvent use. Plasma Technology Inc. has a permit to use PERC, TCE, methylene chloride, nPB or HFE-72DE in their degreaser. IRTA assumed that the HFE was used for two months during the year and that the other four solvents, which have greater solvency, were used for the remainder of the year. The SCAQMD regulation limits the solvents used in open top vapor degreasers to formulations with a VOC content of 25 grams per liter. Plasma Technology has an airless/airtight degreaser and would be allowed to use HFE-72DE which has a high VOC content. Navigation Systems Division has a permit that allows the use of HCFC-225, TCE and nPB and that company also has an airless/airtight degreaser. It was assumed that the company uses HCFC-225 for half the year. Daico Industries uses HFE-7100; an MSDS for the material, a blend of two isomers, is shown in Appendix A. There was no information available on the identity of the solvent used in three of the Northrup Grumman degreasers or the Pratt & Whitney degreaser. It was assumed that these degreasers do not use GHG solvents.

Table 2-14 Vapor Degreasers Using GHG Solvents in SCAQMD Jurisdiction	
Company	Solvent Type
Vacco Industries	HCFC-225
Navigation Systems Division	HCFC-225 and non-GHG
Plasma Technology Inc.	HFE-72DE and non-GHG
The Aerospace Corp.	HCFC-225
Bryant Racing Inc.	HCFC-225
Raytheon Company	HCFC-225
	HCFC-225
Daico Industries	HFE-7100
Shimadzu Precision Instruments, Inc.	HCFC-225
Western Digital Corp.	HCFC-225
Prototype and Short-Run Services, Inc.	HCFC-225
Brasstech Inc.	HCFC-225
L-3 Communications Electron Tech Inc.	HCFC-225 or HFC-4310
Microsemi Corp-Power Mgmt Grp.	HCFC-225
NMB Technologies Corp.	HCFC-225
	HCFC-225
	HCFC-225
Northrop Grumman Systems	HCFC-225
	HCFC-225
	NA*
	NA*
	NA*
Tri-Star Electronics	HCFC-225
Pratt & Whitney Rocketdyne, Inc.	NA*

*NA is not available

Table 2-15 shows the GHG solvent emission limits for the vapor degreasers used by each of the companies. It also shows the GWP weighted emissions of the GHG solvents. There was no information on usage or emissions for Brasstech Inc., L-3 Communications Electron Tech. Inc. and NMB Technologies Corp., so IRTA assumed that each company emitted the average annual amount from the other facilities using HCFC-225. L-3 Communications Electron Tech. Inc. is allowed to use both HCFC-225 and HFC-4310. IRTA assumed the company uses HCFC-225 exclusively; the VOC limit on solvents used in open top vapor degreasers is low and HFC-4310 requires a higher VOC content to clean adequately. For Navigation Systems Division, it was assumed that the company used half the annual average usage of HCFC-225 since the company also uses non-GHG solvents.

Table 2-15 Estimated Weighted Emissions of GHG Solvents in SCAQMD Jurisdiction		
Company	Solvent Emission Limit	GWP Weighted Emissions (metric tons CO2e/yr)
Vacco Industries	2 pounds/day	123
Navigation Systems Division	1,731 pounds/yr	291
Plasma Technology Inc.	20 gal/mo	2
The Aerospace Corp.	4,368 pounds/yr	733
Bryant Racing Inc.	239 pounds/yr	40
Raytheon Company	4,914 pounds/yr	825
	4 gal/day	3,168
Daico Industries	8 gal/mo.	30
Shimadzu Precision Instruments, Inc.	1,960 pounds/yr	329
Western Digital Corp.	7.6 gal/mo.	198
Prototype and Short-Run Services, Inc.	12 gal/mo.	313
Brasstech Inc.	3,461 pounds/yr	624
L-3 Communications Electron Tech Inc.	3,461 pounds/yr	624
Microsemi Corp-Power Mgmt Grp.	9 gal/mo.	234
NMB Technologies Corp.	3,461 pounds/yr	624
	3,461 pounds/yr	624
	3,461 pounds/yr	624
Northrop Grumman Systems	3.5 pounds/day	214
	3.5 pounds/day	214
Tri-Star Electronics	55 gal/mo	1,432
Total		11,266

2.2.3.6. Summary of Weighted GHG Solvent Emissions

Taking into account the GHG solvents emitted in the California air districts, Table 2-16 summarizes the results. The values show that weighted emissions of GHG solvents used for vapor degreasing in California amount to more than 19 thousand metric tons of carbon dioxide equivalent per year or about 0.02 million metric tons of carbon dioxide equivalent.

Table 2-16 Estimated Emissions of GHG Solvents in Vapor Degreasing Applications in 2010	
Air District	GWP Weighted Emissions (metric tons CO2e/yr)
San Diego County APCD	5,344
Bay Area AQMD	2,810
SCAQMD	11,266
Total California	19,420

2.2.4. Business As Usual (BAU) Emission Projections

There is one major change that will occur between 2010 and 2020 that will change the mix of solvents used in vapor degreasers. In 2015, production and importation of HCFC-225 will be banned because the solvent contributes to stratospheric ozone depletion. As discussed earlier for film cleaning, use of the solvent is not banned so there may be stockpiled materials for perhaps two years after the ban. As was the case when TCA and CFC-113 production were banned, some users will begin examining alternatives a few years before the scheduled ban and others may not switch to alternatives until the supply of HCFC-225 is depleted. For purposes of analysis, it will be assumed that all HCFC-225 users will adopt alternatives by 2020. Apart from the production ban of HCFC-225, there is no reason to expect an increase or decrease in use of solvents in vapor degreasing.

Slightly more than half the companies using GHG solvents in the jurisdiction of San Diego and the Bay Area use HCFC-225. The vast majority of the GHG solvent users in the South Coast Basin use HCFC-225. The regulations in the SCAQMD, as discussed earlier, restrict the VOC content of the solvents used in open top vapor degreasers. The regulations in SCAQMD also do not allow the use of chlorinated solvents (like TCE and PERC) in open top vapor degreasers. Companies in the South Coast Basin will have to work within these restrictions when they select an alternative cleaning method when HCFC-225 is phased out.

2.2.4.1. SCAQMD Jurisdiction

Baseline 2010 emissions of HCFC-225 in the SCAQMD amount to 10,319 metric tons of carbon dioxide equivalent. IRTA has visited several HCFC-225 users over the last several years. Many of these users could convert to water-based cleaning systems if they did the testing required to find suitable cleaning equipment and a water cleaner appropriate for their operation. Most of the HCFC-225 users do not believe they can use water cleaning systems, however, so some of them will not be willing to do the testing. The production ban on HCFC-225 will bring this issue to a head and force the HCFC-225 users to reevaluate their process. For the BAU scenario for 2020, IRTA assumed that one-half of the HCFC-225 users will actually undertake the testing program and successfully convert to water-based cleaning systems and, further, that half the HCFC-225 emissions will be eliminated as a result of the conversion.

Companies in the South Coast Basin using HCFC-225 that decide they want to continue using a vapor degreasing process will have to purchase an airless/airtight vapor degreaser. They can then use either PERC, TCE or nPB on the one hand or HFE/HFC with DCE on the other hand. Again, the reason they have to use an airless/airtight degreaser with the HFE or HFC is that the cleaning power of the solvents is very low and it needs enhancement with the DCE which is a VOC. Virtually all users who purchase an airless/airtight degreaser will opt to use PERC, TCE or nPB. These solvents clean more effectively than the HFC or HFE blends and they are far less expensive. For the BAU scenario, IRTA assumed that half the HCFC-225 users in the South Coast Basin will purchase airless/airtight degreasers and use solvents like PERC, TCE or nPB. These conversions eliminate emissions of HCFC-225 altogether.

In the South Coast Basin, in 2020, there will be only four companies that use solvents other than HCFC-225 listed in Table 2-14. After the production ban of HCFC-225, Navigation Systems will use the non-GHG solvent the company is permitted to use. L3 Communications will exclusively use the HFC-4310 blend that is about 52 percent HFC-4310. Assuming the company emits the allowed 3,461 pounds per year of solvent and a GWP for HFC-4310 of 1,500, the contribution from this company amounts to 1,225 metric tons of carbon dioxide equivalent. Plasma Tech will continue using HFE-72DE and a non-GHG solvent and Daico will continue using HFE-7100 and will contribute 2 and 30 metric tons of carbon dioxide equivalent. Virtually none of these users is likely to convert to other GHG solvents. On this basis, the remaining emissions of GHG solvents in the South Coast Basin in 2020 will be 1,257 metric tons of carbon dioxide equivalent.

2.2.4.2. San Diego APCD and Bay Area AQMD Jurisdiction

Outside the South Coast Basin, in the San Diego area and the Bay Area, HCFC-225 users have more choices. If they have an open top degreaser, they can use nPB or the HFC/HFE blends with DCE because there are no restrictions on the VOC content of solvents used in open top degreasers. There would be more barriers to using PERC or TCE in open top vapor degreasers because the facilities would have to meet certain risk requirements for the two TACs. Outside the South Coast Basin, it was assumed that one-fourth the HCFC-225 use will be converted to water cleaning, one-fourth will be converted to nPB. Thus, one-half of the HCFC-225 use will be converted to non-GHG cleaners. The remaining half will be converted to the HFC or HFE blends. It will be further assumed that half of this GHG solvent use will be converted to an HFC blend and half to an HFE blend. The most commonly used HFC blend is 52 percent HFC-4310. The most commonly used blend of HFE is HFE-71DE which is 50 percent HFE.

In San Diego, baseline 2010 emissions of HCFC-225 amount to 1,745 metric tons of carbon dioxide equivalent. Half will be converted to non-GHG cleaners. Half of the remaining GHG solvent use, or 436 metric tons, will be converted to HFEs and half to HFC-4310. On this basis, emissions of GHG solvents in 2020 in the San Diego area would be 951 metric tons per year of carbon dioxide equivalent.

In the Bay Area, in 2010, emissions of HCFC-225 amount to 1,981 metric tons of carbon dioxide equivalent. Again making the assumptions described above, half of this amount or 991 metric tons will be converted to non-GHG solvents. Half the remaining GHG solvent use will be converted to an HFC-4310 blend and half to an HFE blend. Emissions of the HFC blend will amount to 1,044 metric tons of carbon dioxide equivalent in 2020 and emissions of the HFE blends will amount to 37 metric tons of carbon dioxide equivalent in 2020. Total GHG emissions from HFC-4310 and HFEs in the Bay Area will be 1,081 metric tons per year of carbon dioxide equivalent.

2.2.4.3. Summary of BAU Emission Projections

Table 2-17 summarizes and compares the GHG solvent emissions for 2010 and the 2020 BAU scenario. The values show that there will be a decline of total emissions of GHG solvents emissions from vapor degreasers, from 19,420 to 3,289 metric tons per year of carbon dioxide equivalent under the BAU scenario. This amounts to a reduction of 83 percent over the period. The major reason for the reduction is the production and importation ban on HCFC-225. Many companies that currently use that solvent will adopt not-in-kind alternatives.

Table 2-17
Baseline and BAU Scenario GHG Solvent Emissions in Vapor Degreasing

Air District	GHG Solvent Emissions (metric tons of CO2e/yr)	
	2010	2020
South Coast AQMD	11,266	1,257
Bay Area AQMD	2,810	1,081
San Diego APCD	5,344	951
Total	19,420	3,289

2.2.5. Cost Comparison of Vapor Degreasing Solvents

IRTA performed a cost analysis and comparison of alternatives for the vapor degreasing application. IRTA evaluated three different alternative approaches for cleaning parts. These included using an open top vapor degreaser with HCFC-225, the most commonly used GHG solvent, purchasing and using an airless/airtight degreaser that uses a non-GHG or GHG solvent and purchasing and using a water-based cleaning system.

The case study that will be evaluated for the HCFC-225 vapor degreasing application is a facility that makes contacts and specialty connectors for military and civilian applications. As part of the assembly process, the connectors, which vary in size and have a very small internal diameter, are currently cleaned in an open top vapor degreaser. The company cleans about 1,000 contacts and runs an average of 10 loads through the degreaser per day. The contacts are made of a variety of metals including brass, copper and stainless steel.

2.2.5.1. Using an Open Top Vapor Degreaser With HCFC-225

Many companies in California are currently using HCFC-225 in open top vapor degreasers and this is the baseline case. The company purchases 55 gallons or one drum of HCFC-225 each month or a total of 660 gallons per year. One supplier of HCFC-225 indicates that the current price of a drum of the solvent is $9,800 (Isaacs, 10/2010). On this basis, the annual cost of the solvent is $117,600. The company already has an open top vapor degreaser and, for purposes of analysis, it was assumed that it is paid off.

The vapor degreaser is used for four hours per day. It has a nine kW heater and a one kW ultrasonic generator for a total electric load of 10 kW. Assuming a cost of 12 cents per kWh, the electricity cost is $4.80 per day. The degreaser operates five days a week for 52 weeks a year. On this basis, the total annual electricity cost is $1,248 per year.

The worker who operates the vapor degreaser spends part of the time the degreaser is operating doing other tasks. The total labor time spent for loading and unloading the parts and starting the degreasing cycle is two hours per day or 520 hours per year. At a labor rate of $15 per hour, the annual labor cost is $7,800.

The company must dispose of the waste solvent. About 75 percent of the solvent is lost through emissions and 25 percent goes out as waste. This implies that there is 165 gallons of waste annually. According to one waste hauler (Isaacs, 10/2010), the cost of disposing of a drum of liquid solvent is $225 to $300 and the cost of disposing of the solid contaminants is 90 cents to $1 per pound. Assuming the midpoint of the range, the liquid disposal cost would be $43,313 per year. Assuming a 30 percent contamination level, a liquid density for the solvent of 12 pounds per gallon and the midrange for the solids disposal, the annual cost for the solids disposal amounts to $806. The total disposal cost is $44,119.

The total cost to the company of using the open top vapor degreaser includes the cost of purchasing the solvent, paying for the electricity, paying the worker and the cost of disposal. The total cost amounts to $170,767 per year.

2.2.5.2. Purchasing an Airless/Airtight Degreaser

One of the alternative options is to purchase and use an airless/airtight degreaser and use a non-GHG or a GHG solvent. IRTA obtained a price for a small airless/airtight Tiyoda degreaser from F1 Service Company (Ohkubo, 11/2010). A picture of the degreaser is shown in Figure 2-7. The price of a small F1 system with a chamber that is 12 inches in diameter and a working depth of seven inches is $125,000. Assuming a cost of capital of four percent and a 10 year life for the equipment, the annualized cost of purchasing the F1 system is $13,000.

Use of the airless/airtight degreaser would reduce solvent emissions by at least 90 percent but the amount of waste generated would remain the same. Solvent use would be about 215 gallons per year. According to a solvent supplier, if the solvent is the blend of the HFC or HFE with DCE, the cost for a drum of solvent would amount to $9,800 and the cost of a drum of PERC would be $900 (Isaacs, 11/2010). The cost of purchasing 215 gallons per year in drum quantities would be $38,309 for the GHG solvent and $3,518 for PERC.

Source: F1 Clean Tiyoda

Figure 2-7. F1 Airless/Airtight Vapor Degreaser

The labor time spent in cleaning, the electricity cost and the disposal costs are unlikely to change. On this basis, the total cost of using the airless/airtight degreaser with a GHG solvent would amount to $104,476 per year.

2.2.5.3. Purchasing a Water-Based Cleaning System

A water-based cleaning system suitable for cleaning contacts is offered by a company called Ramco. It has a wash, rinse and dry section. The wash is ultrasonic and the dryer consists of a blower with air knives. A picture of the system is shown in Figure 2-8. The system also has a belt oil skimmer that removes the oil from the wash bath. The cost of the system ranges from $45,000 to $48,000 depending on the features. Assuming the upper bound for the cost, a cost of capital of four percent and a 10 year life for the equipment, the annualized cost of the system amounts to $4,992.

Source: Cleaning Technology Industries

Figure 2-8. Water System for Contact Cleaning

A water-based cleaner made by Brulin is designed to clean multiple metals and would be suitable for cleaning the contacts. An MSDS for the cleaner, called Brulin 1696 B, is shown in Appendix A. The cost of the cleaner is $19 per gallon and an 11 percent concentration would be required. The wash bath has a 40 gallon capacity. In addition to the water-based cleaner, one-tenth of one percent of a copper brightener, at a cost of $20 per pint, would be added to the bath. The wash bath would need to be emptied and replenished every month. On this basis, 4.4 gallons of cleaner would be required each month. The annual cleaner use would amount to 52.8 gallons and the cost would be $1,003 per year. Including a pint of copper brightener each year, the total cost for cleaning materials would be $1,023 annually.

To clean 1,000 contacts per day, the machine would need to operate about four hours per day and the cleaner would be heated to about 135 degrees F. The machine is rated at 90 amps and the voltage requirement is 240 for a total energy use of 86.4 kWh per day. Using a cost of 12 cents per kWh, the electricity cost per day would be $7.78 and the annual cost would be $2,696.

In the case of the water cleaning system, the labor requirement would probably be higher and a worker would likely have to operate the machine for the full four hours of cleaning time each day. Using a labor rate of $15 per hour, the annual labor cost would be $15,600.

The water cleaning bath needs to be changed out every month. The bath has a 40 gallon capacity. On this basis there would be 480 gallons of waste each year. The cost for disposal of water waste amounts to about $1.50 per gallon. The cost of waste disposal would be $720 annually.

The total cost of using the water-based cleaner includes the equipment purchase cost, the cleaner cost, the electricity cost, the labor cost and the disposal cost. This amounts to $25,031 per year.

2.2.5.4. Summary of Vapor Degreasing Alternatives

Table 2-18 presents the annualized cost comparison for the three different options. The cost of using the open top vapor degreaser with HCFC-225 is the highest cost option, largely because of the high solvent emissions and the high solvent cost. The cost of using the alternative HFE or HFC in the airless/airtight degreaser is the next highest cost option. Although emissions are much lower, the solvent cost is still relatively high. The cost of using PERC in the airless/airtight degreaser is lower because the solvent is much less costly. The lowest cost option by far is use of the water-based cleaning system. This option is less than half the cost of using the airless/airtight degreaser with PERC.

Table 2-18 Annualized Cost Comparison for Vapor Degreaser Alternatives				
	Open Top Vapor Degreaser	Airless/Airtight Degreaser		Water-Based Cleaning System
		GHG	PERC	
Annualized Equipment Cost	-	$13,000		$4,992
Solvent/Cleaner Cost	$117,600	$38,309	$3,518	$1,023
Electricity Cost	$1,248	$1,248		$2,696
Labor Cost	$7,800	$7,800		$15,600
Disposal Cost	$44,119	$44,119		$720
Total Cost	$170,767	$91,476	$56,685	$25,031

2.2.6. Alternative 2020 Emission Projection Scenarios

The BAU emission projection estimates were developed based on the likely behavior of GHG solvent users in the different air districts with different regulations, taking into account the phaseout of HCFC-225. Two alternative emission projection scenarios were examined. Under the first scenario, all vapor degreasing GHG solvent users in California would convert to non-GHG solvents or alternative water-based cleaning processes. Under the second scenario, all GHG solvent users would purchase an airless/airtight degreaser and continue using the GHG solvents. The details of each of the alternative scenarios are discussed below.

2.2.6.1. Conversion to Non-GHG Cleaners

Under this alternative projection scenario, GHG solvent vapor degreaser users would convert to water-based cleaning processes or non-GHG solvents. The non-GHG solvents are either TACs or VOCs or both. Most air districts allow limited emissions of TACs and companies converting to a TAC would probably have to purchase an airless/airtight degreaser to be granted a permit. The only non-GHG VOC solvent that could be used in an open top vapor degreaser, because it has no flash point, is nPB. Other VOC solvents, because they do have flash points, would have to be used in an airless/airtight degreaser with a vacuum to prevent ignition or explosion. Although the SCAQMD is currently the only air district with a VOC regulation for vapor degreasers, many of the air districts in California end up adopting regulations similar to the SCAQMD regulations at a later date. Given these conditions, for this scenario, it was assumed that companies converting to a TAC or a VOC solvent would purchase an airless/airtight degreaser.

For this scenario, it was assumed that in 2020, there would be no remaining use of GHG solvents in vapor degreasing applications in the state. All of the GHG solvents would be converted either to water-based cleaners or to alternative non-GHG solvents which would be used in airless/airtight degreasers.

The cost of the conversions for this scenario are shown in Table 2-19. Some users would convert to solvents like TCE, nPB or other VOCs rather than to PERC. The cost of the alternative solvents would vary, depending on the solvent used. The costs of PERC are similar to the cost of TCE and nPB but are probably higher than the cost of commonly used VOC solvents. Thus, the cost of the conversion to PERC may be an upper bound of the cost of converting to an alternative solvent combined with use of an airless/airtight degreaser. The emissions of GHG solvents from this scenario would decline from 19,420 metric tons of carbon dioxide equivalent in 2010 to zero.

Table 2-19 Annualized Cost of Options for Eliminating Emissions of GHG Solvents in 2020		
	Conversion to PERC In Airless/Airtight Degreaser	Conversion to Water-Based Cleaning System
Annualized Equipment Cost	$13,000	$4,992
Solvent/Cleaner Cost	$3,518	$1,023
Electricity Cost	$1,248	$2,696
Labor Cost	$7,800	$15,600
Disposal Cost	$44,119	$720
Total Cost	$56,685	$25,031

2.2.6.2. Use of Airless/Airtight Degreaser With GHG Solvents

Under this scenario, current users of GHG solvents would continue to use them but they would purchase airless/airtight degreasers which would reduce emissions. By 2020, all GHG solvent users in California would no longer use HCFC-225. Some of the HCFC-225 users, as described in the BAU emission projection scenario, will convert to HFCs or HFEs which will be combined with DCE, a VOC. Because of the SCAQMD regulation on VOC content, all users of GHG solvents in the South Coast Basin will already have airless/airtight degreasers. In the two other air districts, virtually all users will be using the GHG solvents in open top vapor degreasers.

Conversion to an airless/airtight degreaser will reduce emissions by an estimated 90 percent. Emissions from such degreasers occur only when they are opened to load parts and emissions at that time are minimal. Based on an emission reduction of 90 percent, 2020 emissions of GHG in the San Diego County APCD would be reduced from 4,551 metric tons of carbon dioxide equivalent to 451 metric tons annually. Emissions of GHG solvents in the Bay Area APCD would be reduced from 1402 to 140 metric tons of carbon dioxide equivalent by universal adoption of airless/airtight degreasers.

Table 2-20 shows the cost comparison for the case of a user with an open top vapor degreaser and a user with an airless/airtight degreaser. The information is a subset of the information in Table 2-18. Although the cost analysis in Table 2-18 for the case of the open top vapor degreaser was for HCFC-225, the cost of the HFC or HFE blends is similar; even though the HFC and HFE themselves are more expensive, the cost of DCE is much lower. The figures of Table 2-20 show that the annualized cost of using the open top vapor degreaser is much higher than the annualized cost of using the airless/airtight degreaser. This follows from the fact that the solvent is very expensive and the airless/airtight degreaser reduces emissions substantially.

Table 2-20 Annualized Cost Comparison for Open Top and Airless/Airtight Degreaser		
	Open Top Degreaser	**Airless/Airtight Degreaser**
Annualized Equipment Cost	-	$13,000
Solvent Cost	$117,600	$38,309
Electricity Cost	$1,248	$1,248
Labor Cost	$7,800	$7,800
Disposal Cost	$44,119	$44,119
Total Cost	$170,767	$91,476

2.2.6.3. Summary of Alternative Projection Options

Table 2-21 summarizes the GHG solvent emissions in 2020 for the BAU and alternative projection scenarios. The values indicate that the scenario for conversion to Not-In-Kind alternatives eliminates GHG solvent emissions altogether in 2020. There is a reduction in GHG solvent emissions of 56 percent in 2020 if users purchase airless/airtight degreasers. Again, because SCAQMD already regulates VOCs in open top vapor degreasers, there is no reduction in GHG emissions in the South Coast Basin.

Table 2-21 BAU and Alternative Projection Scenarios in Vapor Degreasing in 2020			
Air District	GHG Solvent Emissions (metric tons of CO2e per year)		
	BAU Scenario	Conversion to Not-In-Kind Cleaners	Purchase of Airless/ Airtight Degreaser
South Coast AQMD	1,257	0	1,257
Bay Area AQMD	1,081	0	108
San Diego APCD	951	0	95
Total	3,289	0	1,460

2.3. Disk Lubing

One additional application of solvents in California is disk lubing. Although in the past, there was a large manufacturing operation in California, the production capacity has been moved off-shore. There are only a few disk lubing operations left in the state at this point.

All of the hard disks that are manufactured are coated with a lubricant that needs to be applied evenly on the disk surface. This process is critical to the performance of the hard disk. A specialized lubricant is first dissolved in a carrier medium, which is generally a GHG solvent. The disks are lowered into the mixture at a slow controlled speed and the mixture is deposited on the disks. The disks are removed from the bath, again at a controlled rate which determines the thickness of the coating mixture. The carrier, the GHG solvent, is fast drying and it evaporates, leaving behind an even coating of the lubricant.

Historically, PFCs were used as the carrier in these operations. More recently, with increasing concern over the high GWPs of the PFCs, HFC-4310 and the HFEs have been substituted for the

PFCs. Because the alternatives have similar properties, the lubricants have high solubility in them as well and the HFC and HFEs are viable alternatives. There are no regulations that regulate disk lubing as such.

2.3.1. Emission Inventory Baseline

IRTA became aware of two disk lubing operations in California while collecting data on the vapor degreasing applications. Seagate Technology and WD Media, Inc. both use GHG solvents in disk lubing operations and both companies are located in the Bay Area. The Bay Area AQMD permits the equipment as a vapor degreaser even though the disk lubing operation uses the GHG solvents unheated and the GHG solvents are heated to their boiling point in vapor degreasers. It is unlikely there are other disk lubing operations in other parts of California. The Bay Area is the likely location for companies performing this type of activity.

Seagate Technology has two disk lubing operations. The company has moved their production operations out of the country and apparently only performs R&D activities at the facility in Fremont, California. IRTA contacted the company to talk about the usage of GHG solvents but the company would not provide any information. IRTA instead used the information from the Bay Area AQMD permits. According to the permits, one piece of equipment emits a maximum of 148 gallons per year of a PFC; the other emits a maximum of 260 gallons per year of an HFE. Another company, WD Media Inc., uses an HFE in the disk lubing operation and emits a maximum of 50 gallons per year.

The PFC used most often in disk lubing operations is PF-5060. An MSDS for this material is shown in Appendix A. One HFC, HFC-4310, and one HFE, HFE-7100, have both also been used in disk lubing operations. MSDSs for both materials are shown in Appendix A.

Assuming the HFE used by the two companies is HFE 7100 and the PFC used by Seagate Technology is PF 5060, the emissions from the two sources are shown in Table 2-22. The GWP for HFE-7100 is assumed to be 55. GWPs for specific PFCs are not well characterized or available; one source estimates that the GWP for PF-5060 is 7,400 (EPA, 2010). On this basis, total weighted GHG solvent emissions from this category amount to a little more than seven thousand metric tons of carbon dioxide equivalent. The emissions from this category are very high because of the high GWP for the PFC.

Table 2-22
Estimated Emissions of GHG Solvents from Disk Lubing Operations in 2010

Company	GHG Solvent	Emission Limit	Emissions (metric tons of CO_2e)
Seagate Technology, LLC	PF-5060	148 gal/yr	7,044
	HFE-7100	260 gal/yr	81
WD Media Inc.	HFE-7100	50 gal/yr	16
Total			7,141

2.3.2. Business as Usual (BAU) and Alternative Scenario Emission Projections

Since Seagate Technology would not discuss their operations, IRTA has no basis for assuming the emissions in 2020 would be different from those in Table 2-21 for 2010. IRTA also assumed that WD Media would continue to use and emit the same amount of the HFE in 2020. For an alternative scenario, IRTA assumed that Seagate would use HFE-7100 or HFC-4310 instead of PF-5060 for disk lubing. The HFE and the HFC both apparently perform as well as the PFC for disk lubing and there is no reason to expect either chemical would not be suitable for Seagate Technology's R&D testing.

Table 2-23 shows the BAU projection and the alternative projection scenario under the assumption that Seagate Technology uses only the HFE in 2020. Table 2-24 presents the BAU projection and the alternative scenario under the assumption that Seagate Technology uses HFC-4310 in place of the PFC. The values of Tables 2-22 and 2-23 show that conversion from the PFC to the HFE results in a reduction in 2020 over the 2010 baseline of 99 percent. The values of Tables 2-22 and 2-24 show that conversion from the PFC to the HFC results in a reduction in 2020 over the 2010 baseline of 81 percent.

Table 2-21
BAU and Alternative Projection Scenarios in Vapor Degreasing in 2020

Air District	GHG Solvent Emissions (metric tons of CO2e per year)		
	BAU Scenario	Conversion to Not-In-Kind Cleaners	Purchase of Airless/ Airtight Degreaser
San Diego APCD	4,551	-	455
Bay Area AQMD	1,402	-	140
South Coast AQMD	1,257	-	1,257
Total	**7,210**	-	**1,852**

Table 2-24
2020 BAU and Alternative Scenario Emission Projections for Disk Lubing Operations Replacement of PFC with HFC

Company	GHG	Emission Limit	Metric Tons of Carbon Dioxide Equivalent
Seagate Technology, LLC	HFC-4310	148 gal/yr	1,327
	HFE-7100	260 gal/yr	81
WD Media Inc.	HFE-7100	50 gal/yr	16
Total			1,424

2.3.3. Cost Comparison of Alternatives

For the cost analysis and comparison, a case study of using HFE-7100 or HFC-4310 in place of PF-5060 was evaluated. Seagate Technology and their PFC operation was used as the case study. Three cost scenarios were evaluated. These include use of PF-5060, conversion to HFC-4310 and conversion to HFE-7100. In this case, since the GHG materials are used for coating, they do not become contaminated and require disposal in contrast to the vapor degreasing application where they are used for cleaning and the contaminants build up in the bath. In this case, therefore, the emissions are equivalent to use. It makes sense, for the case study, to simply compare the cost of purchasing the different GHG solvents used in the disk lubing process. Other factors like energy costs for the operation and purchase costs of the lubricant are likely to be identical or similar for the different GHG materials.

The cost of HFC-4310 and HFE-7100 are both currently about $17 per pound and the cost of PF-5060 is about $19 per pound (Wolff, 11/2010). The specific gravity of PF-5060 is 1.7 and the specific gravity of HFE-7100 and HFC-4310 are 1.5 and 1.58 respectively. On this basis, Table 2-25 presents the cost of using and emitting 148 gallons per year of the three different carrier materials annually.

Table 2-25
Annual Cost Comparison of GHG Materials for Disk Lubing Operation

	PF-5060	HFE-7100	HFC-4310
Amount of Carrier (pounds)	2,098	1,851	1,950
Cost of Carrier	$39,862	$31,450	$33,150

The values of Table 2-25 show that the highest cost carrier is the PF-5060. Both of the alternatives are lower cost than the PFC. There should be no disadvantage to using the alternative lower GHG materials in the operation. The alternative conversion scenarios reduce the GHG solvent emissions substantially and the cost of using the lower GWP alternatives is lower.

Section 3. Greenhouse Gas Use in Fire Protection Systems

Halons are halogenated chemicals that have been used for many years as gaseous fire extinguishing agents in a range of different fire and explosion protection applications. Halons contribute to stratospheric ozone depletion and they are also GHGs. The advantages of halons are that they are electrically non-conductive, they dissipate instantly without leaving a residue, they are safe for limited human exposure when used properly and they are very efficient in extinguishing fires.

There are five classes of fires and halons are used effectively on three of them. Class A fires are fires in common combustible materials like wood, cloth, paper, rubber and many plastics. Class B fires are fires in flammable liquids, oils, greases, tars, oil-based paints, lacquers and flammable gases. Class C fires are fires that involve energized electrical equipment. Halons are not recommended for use on the other two classes of fires, Class D fires of combustible metals and Class K fires, which involve cooking appliances.

Halons have also been used in fixed systems that are called total flooding systems. In these systems, an extinguishing agent is applied to an enclosed space in order to achieve a concentration of the agent adequate to extinguish the fire. These systems can be operated automatically by detection or other controls, or manually by the operation of a system actuator. Total flooding systems are used to protect electronic and telecommunications equipment like computer facilities, medical facilities, traffic control towers, military applications, oil production facilities, record storage areas and flammable liquid storage areas. Halon 1301 was and still is widely used in these systems. An advantage of Halon 1301 is that it can be used in situations where there is limited human exposure since the material itself is low in toxicity.

Halons have also been used in portable fire extinguishing systems and are referred to as streaming agents in this application. In local application, the agent is applied directly onto a fire or into the area of the fire. The most common method of local application is by manually operated portable or wheeled fire extinguishers. Portable or wheeled fire extinguishers are used in offices, retail stores, manufacturing facilities, homes and aerospace and marine applications. Halon 1211 was and still is extensively used in this application.

Halons are also used in aviation systems for protecting aircraft from fires. Halon 1301 has been is used in systems for lavatory trash receptacles, engines and cargo compartments. Halon 1211 is used in handheld fire extinguishers on aircraft.

The U.S. banned the production and importation of Halon 1211 and Halon 1301 in 1994 under the Clean Air Act in compliance with the Montreal Protocol On Substances That Deplete the Ozone Layer (EPA, undated). Since the halon production bans, new alternatives have been used in place of Halon 1211 and Halon 1301. The halons are still in many of the systems because there has been no reason to replace them. In new systems, however, a range of different alternatives have substituted for the halons.

Alternatives to Halon 1301 in total flooding systems include not-in-kind materials like powdered aerosols, water sprinklers, water mist systems and foams. Carbon dioxide is used in some systems in unoccupied spaces. Inert gases such as argon and nitrogen, are also used in new systems. A range of in-kind alternatives are also used in total flooding systems. PFCs were used as replacement agents in the years after the production ban but are not used in new systems today except in narrow niche applications. The most common Halon 1301 alternatives used today in new systems are HFC-227ea and HFC-125. One additional agent, a perfluoroketone, perfluoroethyl isopropyl ketone or FK-5-1-12, is also now being used in new systems. FK-5-1-12 does not cause ozone depletion and has a very low GWP.

The alternatives that replaced Halon 1211 in portable fire extinguishers include not-in-kind materials like dry powder, carbon dioxide and water. PFCs were used in new fire extinguishers but are no longer used in new equipment today. One HCFC, HCFC-123, is used in new extinguishers. One HFC, HFC-236fa, is also used in new extinguishers today.

The GWPs for the GHG agents used in fire protection are shown in Table 3-1; a few of the agents also contribute to ozone depletion and the ODP is shown as well. The not-in-kind materials and the inert gases have zero GWP so they are not included in the table. The GWPs for the chemicals are given relative to carbon dioxide which has a defined GWP of 1. The ODPs for the chemicals that contribute to ozone depletion are given relative to CFC-11 which has a defined ODP of 1.0.

Table 3-1
Global Warming Potential of GHGs used for Fire Protection

Agent	Chemical Formula	ODP	GWP
CFC-11	CCl_3F	1	4,000
Carbon dioxide	CO_2	0	1
Halon 1211	CF_2ClBr	3	1,300
Halon 1301	CF_3Br	10	6,900
PFC-14	CF_4	0	6,500
PFC-3-1-10	C_4F_{10}	0	7,000
HCFC-123	$C_2HCl_2F_3$	0.01	77
HFC-23	CHF_3	0	11,700
HFC-125	CHF_2CF_3	0	2,800
HFC-134a	CF_3CH_2F	0	1,300
HFC-227ea	CF_3CHFCF_3	0	2,900
HFC-236fa	$CF_3CH_2CF_3$	0	6,300
FK-5-1-12	$C_2F_5C(O)CF(CF_3)_2$	0	~ 1

Sources: U.S. CAR, 2010; IPCC, 2010.

IRTA has divided the GHGs used in fire protection applications into two major categories. These include fixed applications where total flooding systems are used and streaming applications where portable extinguishers are used. Each of these applications is discussed in more detail below. IRTA did not analyze fire protection in aviation applications further since the agents used in this sector are not in fixed California locations and are not likely to be contributing significantly to emissions in the state.

3.1. Fixed Total Flooding Systems

Halon 1301, in addition to acting as an ozone depleting substance, is also a GHG. Although Halon 1301 is no longer used in new total flooding systems, there are still many systems installed in California at various locations. A picture of a typical Halon 1301 total flooding system is shown in Figure 3-1. The 1994 ban applied to production, not use, so when systems are dismantled, the Halon 1301 they contain is sent to a recycler. The recyclers remove the moisture and other contaminants and sell the Halon 1301 back into the market. In cases where users still have installed Halon 1301 systems, the recycled Halon 1301 may be used in servicing to replace leakage or to replace discharges from existing systems. The systems that still contain Halon 1301 represent part of the GHG bank.

Source: Bimbo Bakeries

Figure 3-1. Typical Halon 1301 Total Flooding System

Other GHG agents that have been used in total flooding systems since the Halon 1301 production ban are PFC 3-1-10 and HFC-23. These alternative agents are no longer used in new systems today. One industry source indicates there may be as many as 25 systems left in California that contain the PFCs (Gerard, 1/2011). The only GHGs used now in new total flooding systems are HCFC-125, HFC-227ea and FK-5-1-12 and systems containing these agents also form part of the GHG bank.

3.1.1. Background on Total Flooding Systems

Before 1994, virtually all total flooding system applications relied upon Halon 1301. The halon is referred to as a clean agent which means it does not leave a residue when the system is discharged. This can be very important in cases where expensive equipment requires fire protection. When the ozone depleting substance production ban became effective, many alternatives to Halon 1301 were investigated. As discussed earlier, the alternatives included PFCs and a variety of HFCs. Some of these alternatives were discontinued either because they had very high GWPs, because they posed toxicity problems or because they were not efficient to use in the total flooding system application.

In 1993, a congressional tax was placed on newly produced halons, making them extremely expensive to use. The last Halon 1301 systems were installed in that year. HFC-227ea began to be used in new systems in 1993. HFC-125 was introduced around the same time as HFC-227ea but gained more widespread use in new systems starting in 2004. In the first few years after 1993, some PFC systems were also installed. There was significant concern about the PFCs, however, because of their high GWPs, so no new systems containing them have been installed in California for many years. Only in the last few years has FK-5-1-12 been used in new systems.

Many total flooding systems are in unoccupied spaces or do not contain expensive equipment that may require use of a so-called clean agent. These systems have been converted to not-in-kind alternatives like water mist systems, sprinklers or carbon dioxide. New systems that may be in occupied spaces or have equipment that could be damaged are using clean agents including HCFC-125, HFC-227ea, FK-5-1-12 or an inert gas system. The commonly used inert gas systems are IG-55 which is 50 percent argon and 50 percent nitrogen and IG-541 which is 50 percent nitrogen, 42 percent argon and eight percent carbon dioxide.

An MSDS for Halon 1301, which is bromotrifluoromethane, is shown in Appendix B. MSDSs for HFC-125, called by the tradename FE-25, and HFC-227ea, called by the tradename FM-200, are also provided in Appendix B. The appendix also shows MSDSs for FK-5-1-12, called by the tradename Novec 1230, IG-55, called by the tradename Argonite, and IG-541 which is called by the tradename Inergen.

In the analysis presented here, IRTA used a bottom up method to estimate the current inventory of GHG agents in total flooding systems in California and to estimate the emissions. IRTA worked with a company that installs systems in Southern California to derive estimates of the Halon 1301, HFC, FK-5-1-12 and inert gas system installed bank and emissions (Facilities Protection Systems, 2009 and 2010). The company has an affiliated company in Northern California and together, the two companies may account for as much as 30 percent of the market in California. This approach constituted the bottom-up inventory estimate and the analysis is discussed in more detail below.

3.1.2 Total Flooding System Bank

IRTA's approach to estimating the bank of agents in the inventory in 2010 and projecting the bank of agents in 2020 first involved estimating the number of total flooding systems containing each of the agents used today. Based on an average system charge, the bank of agent in total flooding systems was estimated for 2010. IRTA then estimated the size of the 2020 bank under a BAU scenario.

3.1.2.1. Number of Total Flooding Systems

Before 1993, it is estimated that 5,000 Halon 1301 systems were installed in California. Since then, about 80 percent of these systems, or 4,000, have been decommissioned. When Halon systems are decommissioned, the tank containing the agent is sent to a recycling company where the agent is removed for recycling and reuse. This leaves 1,000 Halon 1301 systems that are still being used in California.

The total number of systems in California has probably not changed over the last 15 years for one major reason. Computer related equipment has become substantially smaller and there has been a movement to modular systems and cloud computing. Companies that have data centers or telecommunications equipment that are protected by total flooding systems have reduced the amount of space they require for their computerized systems. As a result, the size of the protected space has declined and fewer total flooding systems are needed for protection. The decline in the number of systems has been offset by growth in the number of companies adding new systems so the total number of systems has remained approximately constant over the period.

Assuming the total number of systems has remained constant and that there are 1,000 remaining Halon 1301 systems, there are about 4,000 HFC, FK-5-1-12 and inert gas systems today. It is estimated that 3,000 of these systems are HFC systems and about 1,000 are inert gas or FK-5-1-12 systems. As many as 90 percent of the HFC systems are HFC-227ea and 10 percent are HFC-125. On this basis, the total number of HFC-227ea systems amounts to 2,700 and the total number of HFC-125 systems is 300. Over the last few years, FK-5-1-12 has penetrated the market and there may be about 250 systems in California. There are about 750 inert gas systems, 90 percent of which are IG-541 and 10 percent of which are IG-55. The number of IG-541 systems is 675 and the number of IG-55 systems is 75. There may be as many as 25 PFC systems still in place in California.

3.1.2.2 Average System Charge

With the assistance of system installers, IRTA estimated the average system size for each system type to determine the amount of each agent in the bank. The majority of the HFC systems in California are one tank systems which contain between 20 and 1,000 pounds of agent. The average is assumed to be 500 pounds. The average size of a Halon 1301 system is 300 pounds and the average size of an FK-5-1-12 system is 650 pounds. The average room size for the inert gas systems is about 7,000 cubic feet which translates into about eight tanks. This implies an average inert gas system charge of 3,480 cubic feet. The average size of the PFC systems is estimated at 300 pounds.

3.1.2.3. Estimate of Baseline Agent Bank Size

Table 3-2 summarizes the number of systems of each type in California, the average system charge and the size of the bank by agent. The agent with the largest bank is HFC-227ea, which is the most widely used agent in new systems. Halon 1301 systems still account for a fairly large portion of the bank. HFC-125 is not used as widely as HFC-227ea but still accounts for a reasonable portion of the bank. FK-5-1-12 is taking a growing portion of the bank. The remaining PFC systems are a small fraction of the bank.

Table 3-2
Bank of Agents in Total Flooding Systems in California --2010

System Type	System Number	Average System Charge	Bank Size
Halon 1301	1,000	300 pounds	300,000 pounds
HFC-227ea	2,700	500 pounds	1,350,000 pounds
HFC-125	300	500 pounds	150,000 pounds
FK-5-1-12	250	650 pounds	162,500 pounds
PFC	25	300 pounds	7,500 pounds
IG-541	675	3,480 cu.ft	2,349,000 cu.ft.
IG-55	75	3,480 cu.ft.	261,000 cu.ft.

Table 3-3 provides the estimates of the size of the bank, weighted by the GWPs for each of the GHG agents. Referring to Table 3-1, the GWP for Halon 1301 is 6,900. The GWPs for HCFC-227ea and HFC-125 are 2,900 and 2,800 respectively. The GWP for FK-5-1-12 is 1. The GWP for the 12 PFC systems still in place was assumed to be 6,750, the average GWP for PFC-14 and PFC-3-1-10. Since the inert gases are not GHGs, their GWPs are zero.

The values of Table 3-3 show that the total size of the bank, when weighted in terms of carbon dioxide equivalent emissions, is 2.93 million metric tons. The major contributor to the bank is HFC-227ea and Halon 1301 is still a large contributor.

3.1.2.4 BAU Agent Bank Size in 2020

Over the next decade, some of the GHG systems that are used today will be decommissioned because companies move or have different requirements. In other cases, new systems will be installed. The total number of systems is likely to remain constant through 2020; although there will be growth in the number of companies needing systems, this increase will be offset by the continuing trend toward smaller computer related equipment. This implies there will

Table 3-3 Bank Size in Carbon Dioxide Equivalents – 2010			
Agent	Bank Size (pounds)	GWP	Bank Size (metric tons of CO2e)
Halon 1301	300,000 pounds	6,900	939,201
HFC-227ea	1,350,000 pounds	2,900	1,776,316
HFC-125	150,000 pounds	2,800	190,563
FK-5-1-12	162,500 pounds	1	74
PFC	7,500 pounds	6,750	22,970
IG-541	2,349,000 cu.ft.	0	0
IG-55	261,000 cu.ft.	0	0
Total			2,929,124

still be 5,000 systems in that year. This estimate, that the total number of systems will remain constant, is actually conservative and there may, in fact, be a decline in the number of systems over the next 10 years.

The makeup of the systems in place in 2020 will change substantially. Over the last 16 years, there has been an 80 percent decline in the number of Halon 1301 systems. By 2020, assuming the same rate of decline, it is not likely there will be any remaining Halon 1301 systems. The systems are still maintained today with existing recycled Halon 1301 but there is no longer a supply of mechanical and electrical components for the systems. Thus, when components require repair, the systems must be decommissioned. IRTA assumed that all of the Halon 1301 systems remaining today will be replaced by 2020 with other system types. Although there may be as many as 25 PFC systems today, as is the case with Halon 1301 systems, all of these systems will be decommissioned by 2020 and they will be replaced with other types of systems.

Under the BAU scenario, in the absence of regulation, there is likely to be a decline in the number of HFC systems for two reasons. First, the HFCs are perceived to be less “green” than the alternatives. Many companies in California have corporate policies that require a move toward more sustainable operations and greener systems. Second, there have been few, if any, HFC-227 systems installed in the six months or so because of a shortage of fluorspar which is used to manufacture the HFC. This shortage may continue for some time. Of the 3,000 HFC systems, about 20 percent or 600 systems will be decommissioned. Companies replacing these systems or installing new systems will use FK-5-1-12 which has a much lower GWP and is considered to be a greener product; there will be 600 additional FK-5-1-12 systems. Of the 1,000 Halon 1301 systems that remain today, 75 percent or 750 systems will be replaced by FK-5-1-12 and 25 percent or 250 systems will be replaced by one of the inert gas systems. Thus, under the BAU scenario, in 2020, there will be no Halon 1301 systems and no PFC systems, there will be 1,600 FK-5-1-12 systems, there will be 1,000 inert gas systems and there will be 2,400 HFC systems. The HFC systems will still have the same proportions as they do today which indicates that 90 percent or 2,160 will be HFC-227ea and 240 will be HFC-125. For purposes of analysis, it was assumed that the system replacement would occur uniformly over the period since there is no information that would suggest otherwise.

Because there will be no Halon 1301 or PFC systems in 2020 and because the number of HFC systems will decline, the characteristics of the installed base in 2020 will be very different. The number and types of systems in 2020 is shown in Table 3-4.

Table 3-4
Bank of Agents in Total Flooding Systems in California Under BAU Scenario -- 2020

System Type	System Number	Average System Charge	Bank Size
HFC-227ea	2,160	500 pounds	1,080,000 pounds
HFC-125	240	500 pounds	120,000 pounds
FK-5-1-12	1,600	650 pounds	1,040,000 pounds
IG-541	900	3,480 cu ft	3,132,000 cu ft
IG-55	100	3,480 cu.ft.	348,000 cu.ft.

Table 3-5 shows the size of the bank weighted by the GWP for each of the agents. Based on the GWPs of 2,900 for HFC-227ea and 2,800 for HFC-125, the HFC contribution to the bank is almost 1.6 million metric tons of carbon dioxide equivalent. The HFCs under the BAU assumptions, account for virtually the entire bank in 2020.

Table 3-5
Bank Size in Carbon Dioxide Equivalents Under BAU Scenario—2020

Agent	Bank Size	GWP	Bank Size (metric tons of CO2e)
HFC-227ea	1,080,000 pounds	2,900	1,421,053
HFC-125	120,000 pounds	2,800	152,450
FK-5-1-12	1,040,000 pounds	1	472
IG-541	3,132,000 cu ft	0	0
IG-55	348,000 cu ft	0	0
Total			1,573,975

The values of Table 3-3 and Table 3-5 show that there will be a substantial decline of 47 percent in the size of the bank by 2020 under the BAU scenario. Although HFCs with fairly high GWPs will be the major contributors, there are no longer any Halon 1301 or PFC systems. Because the GWPs for Halon 1301 and the PFCs are much larger than the GWPs for the HFCs, there is an overall reduction in the size of the bank.

3.1.3. Agent Baseline Emissions

There are two types of emissions from total flooding systems. First, emissions occur during discharge of a system, either because of a fire or an inadvertent release. One installer indicates that an upper bound estimate of these emissions is 0.5 percent of the installed base (Gerard, 12/2010). Second, emissions occur during refilling to replace leakage losses and during decommissioning of systems. The same installer estimates an upper bound estimate of these emissions at 0.3 percent of the installed base. Using these estimates, the total emissions from total flooding systems amount to 0.8 percent. These estimates are for the systems that are installed currently or have been installed in the last decade or so. Over the years, since Halon 1301 was found to be a significant ozone depleter, the system integrity has been improved. Emissions from older Halon 1301 systems that are still used today and have not been decommissioned, are likely to be higher, perhaps as high as four percent of the installed base. Another source estimates emissions of all agents at two percent of the installed base (EPA, 2004). Since this earlier estimate was made, additional improvements in handling systems and agent have been made and the actual loss for systems installed more recently is likely to be lower. Taking this into account, IRTA used the estimate of 0.8 percent for the emissions of HFCs in 2010 and used the higher estimate of four percent for emissions of Halon 1301 in 2010.

Table 3-6 summarizes the emissions in 2010, the baseline year. The values take into account the four percent emissions from the installed base for Halon 1301 and the 0.8 percent emissions from the installed base for the HFCs, FK-5-1-12 and PFCs. The emissions from FK-5-1-12 are negligible. The total emissions amount to 0.053 million metric tons of carbon dioxide equivalent.

Table 3-6
Baseline Emissions From Total Flooding Systems– 2010

	Emissions (metric tons of CO2e)
Halon 1301	37,568
HFC-227ea	14,211
HFC-125	1,525
FK-5-1-12	-
PFC	184
Total	53,488

3.1.4. Projected Emissions Under BAU Scenario

Emissions of GHG agents in 2020 will be significantly lower than the emissions in 2010 for three reasons. First, there will be no total flooding systems that contain Halon 1301 by then; they will all have been decommissioned. Halon 1301 has a very high GWP and emissions from the older systems containing the agent are higher than for more recently installed systems. Second, there will be no PFC systems remaining and PFCs also have relatively high GWPs. Third, there will be fewer total flooding systems containing the HFCs which also have reasonably large GWPs.

Table 3-7 shows the emissions from total flooding systems for 2020 under the BAU scenario. The values are based on the 0.8 percent figures for emission losses from total flooding systems and the 2020 bank estimates in Table 3-5. Emissions from total flooding systems will amount to 0.013 million metric tons of carbon dioxide equivalent in 2020. Comparing the figures of Table 3-6 and 3-7 shows there will be a total reduction in emissions between 2010 and 2020 of about 76 percent.

Table 3-7 Baseline Emissions From Total Flooding Systems Under BAU Scenario– 2020	
	Emissions (metric tons of CO2e)
HFC-227ea	11,368
HFC-125	1,220
FK-1-5-12	4
Total	12,592

3.1.5. Cost Comparison of Alternative Total Flooding System Agents

IRTA worked with suppliers and system installers to perform a cost analysis and comparison of the five most commonly used agents for fixed total flooding systems. The cost analysis is useful for evaluating policy options involving substitution. IRTA compared the costs of using five different agents including HFC-227ea, HFC-125, FK-5-1-12 IG-55 and IG-541. These are the agents likely to be used in new systems over the next decade. IRTA used two different room volumes to represent a small and large system. The small space was 400 square feet in area with a 10 foot high ceiling for a total of 4,000 cubic feet. The large space was 6000 square feet in area with a 10 foot high ceiling for a total of 60,000 cubic feet.

3.1.5.1. Factors Contributing to System Costs

Two elements that contribute to the cost of using an agent were considered. The first is the installation cost which consists of:

- mechanical equipment costs for items like tanks, nozzles and pressure switches
- electronics costs like control panels and smoke detectors
- electrical labor costs that pay for the electrician and the programming
- mechanical installation costs for the installation labor and piping
- engineering and supervision costs

All of these cost components are the same for each of the five agents except the mechanical equipment cost and the mechanical installation costs. The amount of agent needed varies and is determined by the size of the system and the concentration of agent required to extinguish a fire which is determined by the National Fire Protection Association (NFPA). The difference in the amount of agent required is a function of the extinguishing capability of the agent and the physical properties of the agent. The mechanical equipment cost varies because the agents may require a different number of tanks and different piping. The cost of the mechanical equipment installation costs will be different because of the agent characteristics and mechanical equipment requirements.

The second element that contributes to the cost of using an agent is the recharge cost. If the agent is lost because of an accident or a fire, then the facility will have a recharge cost associated with refilling the equipment. The cost of recharge varies because of the difference in cost of the agent, the amount of agent required and the parts and labor needed for refilling the tank.

For the recharge cost, the number of cubic feet required for the inert gas agents is determined by multiplying the number of cubic feet that is being protected by a factor specified in the NFPA regulations. The number of pounds of the other agents are determined by multiplying the number of cubic feet of space that requires protection by the factor for each agent. The factor for an agent required to protect a given space size is based on the agent's properties and ability to extinguish fires. The cost components of the recharge cost are:

- cost of the agent which depends on the number of tanks that must be refilled
- cost of the parts associated with the recharge
- cost of the labor for the recharge

Costs of using the alternative agents were estimated below. The costs were determined for two types of systems, a small 4,000 cubic foot and a large 60,000 cubic foot system. The costs were compared for each of the agents for new system installations and for recharging existing systems.

3.1.5.2. System Cost Comparison for New System Installations

The costs for the two cases of new system installations are shown in Table 3-8 and Table 3-9. Table 3-8 shows the costs for the 4,000 cubic foot space and Table 3-9 shows the costs for the 60,000 cubic foot space. The amount of agent required determines the number of tanks that require installation and this is determined by the NFPA specifications. The table entries are the cost of the electronics, the electrical, the mechanical equipment, the mechanical installation and the total cost. The only cost components that vary are the mechanical equipment cost and the mechanical installation cost.

Table 3-8
Cost of New System Installation in 4,000 Cubic Foot Space

Cost Element	IG-55	IG-541	HFC-125	HFC-227ea	FK-5-1-12
Electronics	$5,000	$5,000	$5,000	$5,000	$5,000
Electrical	$10,000	$10,000	$10,000	$10,000	$10,000
Mechanical Equipment	$10,000	$13,000	$6,000	$8,000	$9,000
Mechanical Installation	$8,000	$9,000	$7,000	$7,000	$7,000
Engineering & Supervision	$5,000	$5,000	$5,000	$5,000	$5,000
Total Cost	$38,000	$42,000	$33,000	$35,000	$36,000

Table 3-9 Cost of New System Installation in 60,000 Cubic Foot Space					
Cost Element	IG-55	IG-541	HFC-125	HFC-227ea	FK-5-1-12
Electronics	$7,500	$7,500	$7,500	$7,500	$7,500
Electrical	$30,000	$30,000	$30,000	$30,000	$30,000
Mechanical Equipment	$93,500	$124,500	$39,000	$52,000	$67,000
Mechanical Installation	$44,000	$53,000	$15,000	$15,000	$21,000
Engineering & Supervision	$5,000	$5,000	$5,000	$5,000	$5,000
Total Cost	$180,000	$220,000	$96,500	$109,500	$130,500

The values of Table 3-8 and 3-9 show that for small spaces that require protection, the cost of a new installation is roughly comparable across all agents. For large spaces that require protection, the differences in the costs are much more pronounced. The system cost of installation for the inert gases, IG-55 and IG-541, is much higher than the cost of installation for systems based on the other agents. As the system becomes larger, more tanks to hold the inert gas are necessary and this raises the installation cost considerably. The space required for an inert gas system is significantly larger than the space required for the other agents. One advantage that offsets this cost disadvantage to some extent is that the inert agent tanks can be located remotely from the site whereas the tanks of the other agents must be in the room that is being protected. The inert gas tanks could be placed in another part of the building since it is possible to pump them further, as much as 400 feet.

For the larger system, the cost of a new installation for HFC-125 is less than half the cost of a new installation for IG-541 and is slightly more than half the cost of a new installation for IG-55. A comparison of the three non-inert gas agent systems shows that the cost of a new installation for HFC-125 is the lowest of the three and that the cost of a new installation for FK-5-1-12 is the highest. The cost of a new installation for FK-5-1-12 is about 35 percent higher than the cost of a new installation for HFC-125.

The higher cost of FK-5-1-12 systems compared to HFC systems is due to two factors. First, for a given fuel, a larger volume of FK-5-1-12 is required. Second, the cost of manufacturing FK-5-1-12 is higher on a per pound basis than the cost of manufacturing the HFCs.

3.1.5.3. System Cost Comparison for Recharging Existing Systems

As discussed earlier, the cost of recharging a system depends on the cost of the agent, the parts cost and the labor cost. The cost of the agent is determined by its price and by the amount of the agent required in the NFPA regulations to protect a space of a given size.

Tables 3-10 and 3-11 show the costs of the recharge for the 4,000 cubic foot space system and the 60,000 cubic foot space system respectively. Each tank of IG-55 holds 572 cubic feet and each tank of IG-541 holds 435 cubic feet. The fee for filling each tank of IG-55 is $350 per tank; for IG-541, it is $300 per tank. The cost of HFC-125 is about $20 per pound. The cost of HFC-

Table 3-10 Recharge Cost for 4,000 Cubic Foot Space					
	IG-55	IG-541	HFC-125	HFC-227ea	FK-5-1-12
NFPA Factor	0.42	0.46	0.0274	0.0341	0.0379
Amount of Agent	1,680 cf	1,840 cf	110 lb.	241 lb.	281 lb.
Number of Tanks	3	5	1	1	1
Cost of Fill/Agent	$1,050	$1,500	$2,200	$3,288	$4,256
Parts Cost.	$100	$100	$500	$500	$400
Labor Cost	$1,488	$1,488	$1,488	$1,488	$1,488
Total Cost	$2,638	$3,088	$4,188	$5,276	$6,144

Table 3-11 Recharge Cost for 60,000 Cubic Foot Space					
	IG-55	IG-541	HFC-125	HFC-227ea	FK-5-1-12
NFPA Factor	0.42	0.46	0.0274	0.0341	0.0379
Amount of Agent	25,200 cf	27,600 cf	1,644 lb.	2,046 lb.	2,274 lb.
Number of Tanks	45	64	2	2	3
Cost of Fill/Agent	$15,750	$19,200	$32,880	$49,104	$63,672
Parts Cost.	$500	$500	$1,000	$1,000	$1,500
Labor Cost	$7,000	$7,000	$2,976	$2,976	$2,976
Total Cost	$23,250	$26,700	$36,856	$53,080	$68,148

227ea is higher, at about $24 per pound, and the cost of FK-5-1-12 is even higher, at $28 per pound. The factor specified in the NFPA regulations is also given in the tables.

The values of Table 3-10 show that for the small system requiring protection, the recharge cost for the inert gases is lower than the recharge cost for the GHG agents. The values of Table 3-11 show a similar pattern. The cost for recharge for FK-5-1-12 is the highest of the three GHG agents.

3.1.5.4. Discussion of Cost Analysis

The results of the cost analysis show that the cost of a new system installation is comparable for all five agents for small spaces. For larger spaces, the cost of a new installation for the inert gases is substantially higher. If there are no recharge costs over the life of the system, then these conclusions will be valid. As discussed earlier, very few systems are discharged inadvertently or for a fire each year. If there is one recharge over the life of the system, the total cost for system installation and recharge for the small space is still comparable across agents. On this same basis, the total cost for system installation and recharge for the large space is higher for the inert gases but is closer in cost to the GHG gases. If two recharges are required over the life of the system, the costs of using the inert gases and the GHG agents are comparable.

This cost analysis and comparison information is summarized in Table 3-12 for the 4,000 cubic foot system and in Table 3-13 for the 60,000 cubic foot system. The first column is the cost for a new system installation only. The second column is the cost for a new system installation and one recharge over the life of the system. The third column is the cost for a new system installation and two recharges over the life of the system. The correct procedure for comparing the cost over the life of the system would be to amortize the cost over the life of the system and annualize the costs. This approach would change the values slightly; the approach used here is simpler and it provides a good idea of the relative costs.

Table 3-12 Cost Over Life of Small System			
Agent	New System Installation	New System Installation and One Recharge	New System Installation and Two Recharges
IG-55	$38,000	$40,638	$43,276
IG-541	$42,000	$45,088	$48,176
HFC-125	$33,000	$37,188	$41,376
HFC-227ea	$35,000	$40,276	$45,552
FK-5-1-12	$36,000	$51,696	$57,840

Table 3-13 Cost Over Life of Large System			
Agent	New System Installation	New System Installation and One Recharge	New System Installation and Two Recharges
IG-55	$180,000	$203,250	$226,500
IG-541	$220,000	$246,700	$273,400
HFC-125	$96,500	$135,356	$172,212
HFC-227ea	$109,500	$162,580	$215,660
FK-5-1-12	$130,500	$198,640	$266,796

The results of the cost analysis show that the cost of a new system installation is comparable for all five agents for small spaces if there are no discharges over the life of the system. For larger spaces, the cost of a new installation for the inert gases is substantially higher if there are no discharges. If there is one recharge over the life of the system, the total cost for the small space is comparable across agents. If there is one recharge over the life of a system for the large space, the cost of using the inert gases and the FK-5-1-12 is comparable; the cost of using the HFCs is lower. For the small system, if there are two discharges, the cost of using the FK-5-1-12 is higher than the cost of using the other four agents. For the large system, with two recharges, the cost of using the IG-541 system and the FK-5-1-12 are the highest.

<u>3.1.6. Alternative Bank and Emission Projection Scenarios</u>

IRTA examined two alternative scenarios for 2020 projections for the bank and for emissions. Under the first scenario, there would be a complete conversion away from the high GWP HFCs by 2020. Under the second scenario, HFCs will replace all of the Halon 1301 and PFC systems that are still used today. Each of these scenarios is discussed in more detail below.

3.1.6.1. Conversion Away from high GWP HFCs

Under this scenario, new systems would no longer use the high GWP HFCs. 3M is the supplier of FK-5-1-12 and it is an example of an in-kind material that has a very low GWP. 3M is the manufacturer and the company may be investigating other fluoroketones that would be appropriate as fire protection chemicals. DuPont is the supplier of the two HFCs used today in total flooding systems. That company is investigating HFC alternatives that would be suitable for use as agents and would have very low GWPs of close to one.

This scenario assumes that all new system conversions would rely on FK-5-1-12 or new agents developed by 3M and/or DuPont with low GWPs. As assumed under the BAU scenario, 75 percent of the Halon 1301 and PFC systems will be converted to FK-5-1-12 or one of the other new alternatives and 25 percent will be converted to the inert gases. There will be a larger decline in the number of HFC systems than assumed under the BAU scenario. Half of these systems will be converted to FK-5-12-1, other fluoroketone alternatives or other HFCs with GWPs of one. For these systems, it was assumed that the average system charge is the same as it is for FK-5-12-1.

Under these assumptions, Table 3-14 shows the number of systems of each type and the bank size in 2020. Table 3-15 shows the bank size in terms of metric tons of carbon dioxide equivalent for this scenario. The values of Table 3-13 show that the bank in 2020 , under this scenario, is less than one million metric tons of carbon dioxide equivalent, which is 37 percent lower than the BAU bank projection.

Table 3-14
Bank of Agent in Total Flooding Systems Under Alternative Low GWP HFC/Fluoroketone Conversion Scenario -- 2020

System Type	System Number	Average System Charge	Bank Size
HFC-227ea	1,350	500 pounds	675,000 pounds
HFC-125	150	500 pounds	75,000 pounds
Other In-Kind	2,525	650 pounds	1,641,250 pounds
IG-541	900	3,480 cu.ft.	3,132,000 cu.ft.
IG-55	100	3,480 cu.ft.	348,000 cu.ft.
Note: Other In-Kind refers to fluoroketones or HFCs with GWPs of one.			

Assuming emissions amount to 0.8 percent of the installed base, emissions under this alternative projection scenario would be 0.008 million metric tons of carbon dioxide equivalent. Weighted emissions under this scenario would decline by 37 percent compared to emissions in Table 3-7 for the BAU scenario. Use of the high GWP HFCs would decline and they would be replaced with very low GWP in-kind alternatives.

Table 3-15 Weighted Bank Under Alternative Low GWP HFC/Fluoroketone Conversion Scenario – 2020			
Agent	Bank Size	GWP	Bank Size (metric tons of CO2e)
HFC-227ea	675,000 pounds	2,900	888,158
HFC-125	75,000 pounds	2,800	95,281
Other In-Kind	1,641,250 pounds	1	745
IG-541	3,132,000 cu.ft.	0	0
IG-55	348,000 cu.ft.	0	0
Total			984,184
Note: Other In-Kind refers to fluoroketones or HFCs with GWPs of one.			

The costs of using the other in-kind alternatives are not known so a cost for the scenario cannot be determined. The costs of this scenario would not likely be very different from the costs under the BAU projection. There is no reason to expect that alternative in-kind fluoroketones and HFCs with low GWPs would be substantially more expensive, particularly if large quantities of the chemicals were needed to supply the demand.

3.1.6.2. Conversion to high GWP HFCs

As discussed in the baseline bank projection scenario above, all of the systems still using Halon 1301 or PFC will be decommissioned by 2020. This high HFC use scenario assumes that all of these systems will be replaced by HFC-227ea and HFC-125. Ninety percent of the systems will use HFC-227 and 10 percent will use HFC-125, the breakdown assumed for the BAU conversion. There will be the same number of inert gas and FK-5-1-12 as there are in the 2010 baseline bank estimates.

On this basis, Table 3-16 presents the number and types of systems and the size of the bank in 2020. Table 3-17 presents the bank size in carbon dioxide equivalents under these assumptions. The values show that the size of the bank in 2020 under this scenario is about 2.64 million metric tons of carbon dioxide equivalent. This can be compared with the 2010 bank which was estimated at 2.93 million metric tons of carbon dioxide equivalent. The 2010 bank is large because a significant portion of the systems still contain Halon 1301 which has a higher GWP than the HFCs. It can also be compared with the bank for the BAU scenario which amounts to 1.57 million metric tons of carbon dioxide equivalents. The BAU bank is smaller because the Halon 1301 and PFC systems and even some of the HFC systems are converted to the inert gases and to FK-5-12-1.

Weighting the bank by the GWP for each agent and assuming emissions amount to 0.8 percent of the installed base, emissions under this scenario are 0.021 million metric tons. This is significantly higher than the emissions of 0.012 under the BAU scenario.

Table 3-16 Bank Size Under Alternative High HFC Conversion Scenario – 2020			
System Type	System Number	Average System Charge	Bank Size
HFC-227ea	3,623	500 pounds	1,811,500 pounds
HFC-125	402	500 pounds	201,000 pounds
FK-5-1-12	250	650 pounds	162,500 pounds
IG-541	675	3,480 cu.ft.	2,349,000 cu.ft.
IG-55	75	3,480 cu.ft.	261,000 cu.ft.

Table 3-17 Bank Size in Carbon Dioxide Equivalents Under Alternative High HFC Conversion Scenario – 2020			
Agent	Bank Size	GWP	Bank Size (metric tons of CO2e)
HFC-227ea	1,811,500 pounds	2,900	2,383,553
HFC-125	201,000 pounds	2,800	255,354
FK-5-12-1	162,500 pounds	1	74
IG-540	2,349,000 cu.ft.	0	0
IG-55	261,000 cu.ft.	0	0
Total			2,638,981

3.2. Portable Fire Extinguishers

As discussed earlier, most clean agent portable handheld and wheeled fire extinguishers in the past relied upon Halon 1211. When the production ban became effective, most applications where clean agents were not necessary were converted to non-in-kind alternatives like dry chemical, water and foam, wet chemical and water mist. There are still many Halon 1211 portable fire extinguishers in use today in commercial buildings, computer rooms, electronic spaces, communication facilities, museums, marine, utility and rail industries. A typical halon portable fire extinguisher is shown in Figure 3-2 and an MSDS for the material, which is bromochlorodifluoromethane, is provided in Appendix B.

Halotron I was developed to replace Halon 1211 and it is the most widely used alternative streaming agent. Like Halon 1211, it can be used on A, B and C fires. The material is a blend of about 97 percent HCFC-123, two percent PFC-14 and one percent argon (Hughes Associates, 2009). An MSDS for Halotron I is shown in Appendix B. The figures of Table 3-1 indicate that HCFC-123 has a GWP of 77 and PFC-14 has a GWP of 6,500. On this basis, assuming a zero GWP for argon, the GWP of Halotron I is about 205. It is not strictly correct to calculate a weighted average of the GWPs for an agent that is a combination of two GHGs. Each GHG with its GWP should be considered separately. Treating them separately and summing their contribution to the bank or emissions, however, will lead to the same results as using a weighted average for the GWP. Recognizing this, a weighted average GWP was assigned to Halotron I for the analysis that follows.

Source: Amerex Product Catalog

Figure 3-2. Typical Halon 12-11 Portable Fire Extinguisher

The other alternative that has been used in portable streaming systems for A, B and C fire suppression is HFC-236fa which has a GWP of 6,300; an MSDS for this agent, which is called by the tradename FE-36, is shown in Appendix B. These GWPs can be compared with the GWP of 1,300 for Halon 1211. To a small extent, another agent called FM-200 which is based on HFC-227ea, is used in portable fire extinguishers; use of this agent is very small, however, and it is ignored in the analysis that follows.

3.2.1. Background on Portable Fire Extinguishing Systems

When the production ban became effective, virgin Halon 1211 could no longer be used in portable fire extinguishers. Many such systems were in place, however, and recycled Halon 1211 is still used today to service them. Halon 1211 is recycled by several companies and new extinguishers are still manufactured for use with recycled Halon 1211.

For the so-called clean streaming agents used today, including Halon 1211, Halotron I and HFC-236fa, portable handheld and wheeled systems are available in a range of different sizes. As is true for total flooding systems, the different agents have different characteristics and varying amounts of the agents are required to protect a space of a given size. Most Halon 1211 systems are available in sizes ranging from 1.25 pounds to 20 pounds. Fire extinguishers based on Halotron I range in size from 1.4 pounds to 15.5 pounds. Fire extinguishers based on HFC-236 range from 2.5 pounds to 13.25 pounds in size. One supplier indicates that clean agents, without taking into account carbon dioxide, represent between one and three percent of the portable extinguishers that are used in California (Vallette, 8/2009); another source indicates clean agents account for seven percent (Gilbert, 12/2010).

3.2.2 Streaming Agent Bank and Emissions

IRTA conducted a bottom-up estimate of the bank of portable fire extinguishers for California. This involved estimating the amount of each of the agents used in portable extinguishers in California and estimating the number of fire extinguishers by holding discussions with installers, companies who service fire extinguishers, recyclers and suppliers.

3.2.2.1. Portable Extinguisher Bank in 2010

There may be as many as 28,000 fire extinguishers containing high GHG compounds in California (Sherley, 2010). Assuming an average fire extinguisher size of nine pounds, the amount of agent in portable fire extinguishers in California is estimated at 252,000 pounds. Most sources agree on the approximate breakdown of the agent use in California. One company that installs and services extinguishers estimates that 75 percent of the agent is Halon 1211, 20 percent of the agent is Halotron I and five percent is HFC-236 (Gilbert, 12/2010). Another company that services and installs systems estimates the breakdown at 80 percent Halon 1211 and 20 percent Halotron I (Vallette, 8/2009); this company does not offer HFC-236 so the chemical is not included in his estimates. A third company estimates the breakdown at 75 percent Halon 1211, 20 percent Halotron I and five percent HFC-236 (Sherley, 11/2010).

At one stage, there were portable fire extinguishers containing HFC-227ea and PFCs in California. One source indicates there are not likely to be any systems containing those agents any longer (Sherley, 11/2010).

Taking these estimates into account and the figure for the total amount of agent, IRTA assumed that 75 percent of the agent in portable extinguishers is Halon 1211, 20 percent is Halotron I and five percent is HFC-236. On this basis, Table 3-18 presents estimates of the bank of streaming agent in 2010 weighted according to their GWPs.

Table 3-18
Bank of Streaming Agents in California – 2010

Agent	Number of Extinguishers	Amount of Agent (pounds)	GWP	Bank Size (metric tons of CO2e.)
Halon 1211	21,000	189,000	1,300	111,419
Halotron I	5,600	50,400	205	4,688
HFC-236	1,400	12,600	6,300	36,016
Total	28,000	252,000	-	152,123

3.2.2.2. Portable Extinguisher BAU Bank Size in 2020

Two events will influence the size and makeup of the bank in the future. First, the amount of Halon 1211 available for portable fire extinguishers will continue to decline. One source estimates that the amount of Halon 1211 used in fire extinguishing in California will decline by 90 percent between 2000 and 2020; the source also estimates there will be a decline of 30 percent between 2010 and 2020 (Sherley, 11/2010). Second, new production of HCFC-123 will decline substantially by 2015 and must effectively cease in 2020 under the Montreal Protocol agreements. Since HCFC-123 is the major ingredient of Halotron I, only recycled HCFC-123 will be able to be used thereafter. There should be no decline in the use of Halotron I over the next 10 years because new Halotron I can still be used and there will be ample recycled agent available.

Companies that are removing Halon 1211 systems currently are simply decommissioning them and often replacing them with dry chemical systems. As the cost analysis below indicates, the cost of a Halon 1211, Halotron I or HFC-236fa system is very high and companies are simply not willing to pay for them unless it is essential. Although carbon dioxide systems are also clean agents, these systems are not rated for use on Type A fires so users are not converting to that technology; they are simply forgoing the clean agent option. The BAU projection assumes there will be no decline in the use of Halotron I between now and 2020. The use of HFC-236 is very limited and the bank in 2020 will remain the same as the bank in 2010.

Assuming there will be a decline of 30 percent in the number of Halon 1211 systems and constant continuous use of the other two agents, Table 3-19 provides estimates of the 2020 bank under the BAU scenario. Comparing the values of Tables 3-18 and 3-19 indicates that there will be a decline in the overall weighted agent bank of about 22 percent between 2010 and 2020.

Table 3-19
Bank of Streaming Agents in California Under BAU Scenario – 2020

Agent	Number of Extinguishers	Amount of Agent (pounds)	GWP	Weighted Agent (metric tons of CO2e)
Halon 1211	14,700	132,300	1,300	78,035
Halotron I	5,600	50,400	205	4,688
HFC-236	1,400	12,600	6,300	36,016
Total	21,700	195,300	-	118,739

3.2.2.3. Baseline and BAU Projected Emissions

One source that installs systems in California estimates emissions during fires of 0.5 percent of the installed base, two percent for accidental discharges and one to 2.8 percent from leakage (Sherley, 11/2010). Another source indicates that emissions of Halon 1211 for inadvertent discharges and fires amount to about one ton per year (Chelman, 12/2010). This translates into emissions of about 1.8 percent of the installed base and this value excludes leakage. Another source estimates that overall emissions from streaming agents amount to about four percent of the installed base each year (Cortina, 2/2011). These values are reasonably consistent with one another.

Using a value of four percent of the installed base for overall emissions, Table 3-20 provides emissions for each of the agents and emissions weighted in terms of their GWPs for 2010. The values assume the four percent loss for each of the individual agents.

Table 3-20
Emissions and Weighted Emissions of Streaming Agents – 2010

Agent	Emissions (pounds)	GWP	Weighted Emissions (metric tons of CO2 equiv.)
Halon 1211	7,560	1,300	4,459
Halotron I	2,016	205	188
HFC-236fa	504	6,300	1,441
Total	10,080	-	6,088

The figures of Table 3-20 show that the dominant weighted emissions are of Halon 1211. This follows from the fact that it accounts for 75 percent of the installed base currently. Weighted emissions for HFC-236fa are also significant; even though this agent accounts for only a small percentage of the installed base, its GWP is very high. The total weighted emissions for 2010 are somewhat more than six thousand metric tons of CO2 equivalents. This can be compared with the baseline emissions from total flooding systems of 53,488 metric tons of carbon dioxide equivalent in Table 3-6.

There is no reason to expect the percentage emissions to decline by 2020. On this basis, assuming emissions still represent four percent of the installed base, Table 3-21 shows the emissions under the BAU scenario for 2020. Comparing the values of Tables 3-20 and 3-21, there will be a weighted emission reduction of 22 percent over the period 2010 to 2020.

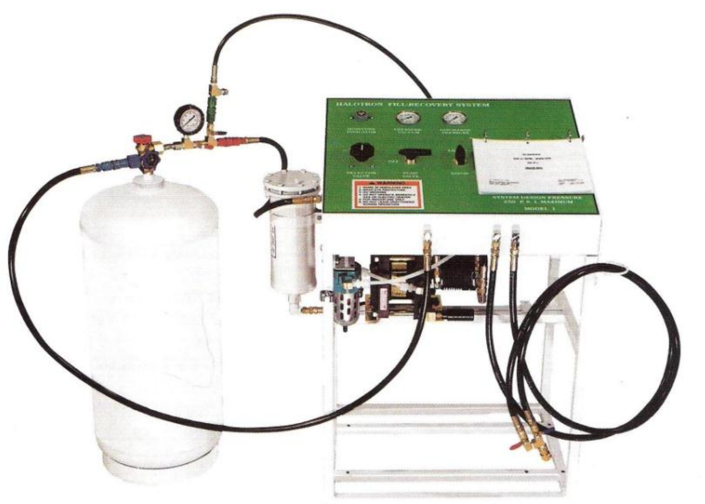
Table 3-21
Emissions and Weighted Emissions of Streaming Agents Under the BAU Scenario – 2020

Agent	Emissions (pounds)	GWP	Weighted Emissions (metric tons of CO2e)
Halon 1211	5,292	1,300	3,121
Halotron I	2,016	205	188
HFC-236fa	504	6,300	1,441
Total	7,812	-	4,750

3.2.3. Cost Comparison of Alternative Streaming Agents

IRTA conducted a limited cost analysis and comparison of the alternative streaming agents which should be useful for comparing policy options. Halon 1211, Halotron I and HFC-236fa systems are expensive to install compared with the non-GHG alternatives. These materials are generally only used when it is absolutely necessary. In a small space of about 2,000 square feet where fire protection is needed, two extinguishers would be required. In a larger space of about 5,000 square feet, five extinguishers would be necessary. The cost of installing one of the GHG agent fire extinguishers is about $500 and it is the same for all three agents. In contrast, the cost of installing a dry chemical fire extinguisher is about $75 (Cranston, 11/2010). As mentioned earlier, there is currently a movement away from the GHG agents to the dry chemical systems because of the high cost of the GHG agents.

Under NFPA-10, every six years, the GHG stored pressure extinguishers must be emptied and subjected to a maintenance procedure. The agent is emptied into a recharge/recovery system and a bulk supply cylinder with sufficient empty capacity to accept the contents of the extinguisher (Amerex, 2008). A picture of one of the recycling machines that is used to process the agent, a machine made by Getz, is shown in Figure 3-3. Companies servicing the extinguishers must have one machine for processing Halon 1211 and another separate machine for processing Halotron I. Machines for Halon 1211 can also be modified to process Halotron I but each machine must be dedicated to a particular agent. The maintenance procedure is carried out and recycled agent is put back into the fire extinguisher. Every 12 years, the extinguisher must be evacuated and undergo hydrostatic testing to ensure it is not leaking. The most common source of leaks is valves or stems.



Source: Getz Manufacturing, www.getzmfg.com

Figure 3-3. Getz Machine for Recovering Halotron I

IRTA obtained cost estimates for conducting the six and twelve year maintenance from two companies who offer the service. One company indicates the cost of either service amounts to $25 for the Halon 1211, HFC-236fa and Halotron systems and $15 for dry chemical (Cranston, 11/2010). Another service company indicates the cost of servicing an extinguisher containing one of the three clean agents at $26 and the cost of servicing an extinguisher containing dry chemical at only $6 (Gilbert, 12/2010). If the extinguisher is found leaking, replacement of agent may be necessary and would be an additional cost. The cost of replacing one of the clean agents is estimated at $12 per pound (Cranston, 2/2011).

The case studies used for the cost analysis are a company that requires two portable fire extinguishers in a 2,000 square foot data room and a company that requires five portable extinguishers in a 5,000 square foot space. The cost of installing two clean agent extinguishers is $1,000 for the two extinguishers and $2,500 for the five extinguishers. The cost of installing two and five dry chemical extinguishers is much lower, at $150 and $375 respectively.

Assuming a life for the portable extinguishers of 20 years, two six year tests and one twelve year test must be conducted. The cost to the 2,000 square foot facility for conducting the testing for two clean agent portable extinguishers is estimated at about $150. The cost to the 5,000 square foot facility for the clean agent testing is about $375. Taking the midpoint for the estimates of the cost of the test for the dry chemical extinguishers at $10.50, the cost to the 2,000 foot facility and the 5,000 foot facility for the testing would be $63 and $158 respectively.

Table 3-22 summarizes the cost of installing and testing the extinguishers over the 20 year life of the systems. The total cost for both sizes of facility is more than five times higher for the clean agent extinguishers than for the dry chemical extinguishers. If some of the agent has

Table 3-22
Cost Comparison for Portable Fire Extinguishers

	2,000 Square Foot Space		5,000 Square Foot Space	
	Clean Agent	Dry Chemical	Clean Agent	Dry Chemical
Installation Cost	$1,000	$150	$2,500	$375
Testing Cost	$150	$63	$375	$158
Total Cost	$1,150	$213	$2,875	$533

leaked, the cost for the clean agent system over the lifetime would be even higher. The correct approach for conducting the cost analysis would be to amortize the costs over the life of the system and annualize the cost. The approach used here is simpler and it does give a representative cost comparison for the agents.

3.2.4. Alternative Bank and Emission Projection Scenarios

IRTA examined two alternative bank and emissions projection scenarios for streaming agents. Under the first scenario, there will be a reduction in the use of Halotron I over the next decade because production of the agent is scheduled to decline significantly in 2015. Users, in anticipation of the ban, will begin moving away from the Halotron I. Between 2010 and 2020, there will be a reduction in the use of the agent of 20 percent. Three-fourths of the Halotron I will be converted to dry chemical extinguishers and one-fourth will be converted to HFC-236fa.

Table 3-23 presents the results of this alternative scenario for the 2020 bank and emissions for the three agents. Comparing the values of Table 3-18 and 3-23 shows that there will be a decline of 18 percent in the weighted bank between 2010 and 2020 under this scenario.

Comparing the figures of Table 3-20 and 3-23 shows a similar decline in weighted emissions between 2010 and 2020. Comparing the values of Table 3-19 and 3-23 shows that under this scenario, the weighted 2020 bank is larger than the weighted bank under the BAU scenario. This follows from the fact that the GWP for HFC -236fa is higher than the GWP For Halotron I which it is replacing.

Table 3-23
Declining Halotron I Alternative Bank and Emission Scenario – 2020

Agent	Bank (pounds)	Weighted Bank (metric tons of CO2e)	Emissions (pounds)	Weighted Emissions (metric tons of CO2e)
Halon 1211	132,300	78,035	5,292	3,121
Halotron I	40,320	3,750	1,613	150
HFC-236fa	15,120	43,220	605	1,729
Total	-	125,005	-	5,000

The manufacturer has commissioned a study that argues for the continued use of HCFC-123, the major ingredient of Halotron I, because of its relatively low GWP of 77 (Hughes Associates, 2009). There are currently no alternatives on the immediate horizon because it takes at least five years for an agent to undergo all the required testing and be qualified for use in this application. Although major manufacturers are undoubtedly investigating in-kind alternatives, they will take some years to penetrate the market. Under the second alternative scenario, IRTA assumed that either an exemption is approved for continued use of HCFC-123 or one or more low GWP alternatives is qualified within the next five years. All of the Halon 1211 and HFC-236fa extinguishers will require at least one six year maintenance procedure during the next 10 years. If Halotron I obtains an exemption or if low GWP alternatives are developed, these materials could replace all of the extinguishers using Halon 1211 and HFC-236fa that are used today.

Table 3-24 shows the weighted bank and weighted emissions for 2020 based on this scenario under the assumption that other in-kind alternatives have the same GWP (approximately 205) as Halotron I. Comparing the values of Table 3-21 and 3-24 shows that under this scenario, there will be an 85 percent reduction in weighted emissions from the BAU emissions scenario. The reduction might even be greater because the Halotron I and potential alternative low GWP agents are expensive and there is a conversion to dry chemical extinguishers that is taking place today and this movement is likely to continue in the future. Since dry chemicals have a zero GWP, the reduction in weighted emissions would be even greater than that shown in Table 3-24 if there is more conversion to dry chemical.

Table 3-24 Conversion to Halotron I or Other Low GWP Agents Alternative Bank and Emission Scenario – 2020				
Agent	Bank (pounds)	Weighted Bank (metric tons of CO2e)	Emission (pounds)	Weighted Emissions (metric tons of CO2e)
Halotron I Or other Low GWP Agent	195,330	18,168	7,813	727

3.3. Other Emissions From Fire Protection Applications

When production of the Halons was banned, companies began developing alternative in-kind clean agents which were introduced into the market over the last 25 years. As discussed earlier, the bank of halons, PFCs, HFCs and FK-5-1-2 is very large depending on when the agent began being used and emissions are relatively low. Over the last several years, a vigorous market for recycling and reusing the clean agents has developed because of their high value in use. There are six companies in the U.S. that currently recycle one or more of the agents. Most of the recyclers recycle all of the agents but one, Pacific Scientific, that is located in California, recycles only Halon 1301 from aviation applications.

Three of the six recycling companies have facilities in California. Pacific Scientific performs all of their recycling operations in California. Another company, H3R, is also based in California and has their recycling operation there. The third company, CSI Fire Equipment, has facilities in California but does the recycling of the agents at plants in other parts of the country.

There are emission losses when the agents are recycled. Various sources estimate this loss at less than one percent of the amount of agent recycled (Cortina, 2/2011). Pacific Scientific, the one recycler that processes only Halon 1301, has an estimated annual recycling volume of 100,000 pounds per year (Richardson, 2008). Considering the other recycler, H3R's plant in California may process as much as one-fifth of the market. Agents processed by this facility include Halons, HFCs and FK-5-1-12.

For total flooding systems, over the next 10 years, the installed base of Halon 1301 will decline by 30,000 pounds per year, assuming a uniform decline as illustrated by the figures of Table 3-2 and Table 3-4 for the BAU projection. Pacific Scientific, the company that exclusively recycles Halon 1301 from the aviation industry, recycles 100,000 pounds of Halon 1301 annually. The installed base of HFC-227ea will decline by 8,100 pounds per year over the period and the installed base of HFC-125 will decline by 3,000 pounds per year. The installed base of the PFCs will decline by 750 pounds per year. For the analysis, it was assumed that all of the agent used in total flooding systems that comes from decommissioned systems will be recycled and that H3R, the non-aviation recycler with a plant in California will recycle 20 percent of these amounts.

For streaming agent applications, the values of Tables 3-18 and 3-19 show that the bank of Halon 1211 will decline by 56,700 pounds over the next 10 years. The banks for Halotron I and HFC-236 will remain constant over the period. Assuming the bank of Halon 1211 declines uniformly over the period, the volume available for recycling when systems are dismantled will amount to 5,670 pounds per year. Assuming the California recycler processes 20 percent, the volume recycled in California is 1,134 pounds annually.

Table 3-25 shows the recycling losses under these assumptions. Applying the one percent figure to the volume processed indicates that emissions amount to 3,359 metric tons of carbon dioxide emissions per year or .003 million metric tons of carbon dioxide equivalent annually. The emissions are dominated by the Halon 1301 from aviation applications.

Table 3-25
Annual Recycling Volume in California

Agent	Recycled Agent	GWP	Recycled Agent	Emissions
	(pounds/year)		(metric tons of CO2e)	
Halon 1301	106,000	6,900	331,851	3,319
HFC-227ea	1,620	2,900	2,132	21
HFC-125	600	2,800	762	7
PFC	150	6,750	459	5
Halon 1211	1,134	1,300	669	7
Total			335,873	3,359

Section 4. Greenhouse Gas Use in Other Applications

The major applications of the GHGs included in this report were discussed in earlier sections. The solvent applications, including film cleaning, vapor degreasing and disk lubing, were analyzed in Section 2. Fire protection applications of GHGs, including fixed total flooding systems and portable extinguishers, were analyzed in Section 3. This section identifies a few other applications of GHGs which are generally lower use and which rely on stockpiled materials. These applications are discussed below.

4.1. Dry Cleaning of Garments

PERC is the major solvent that has been and is used for the dry cleaning of clothing and other fabrics. CARB has adopted an Airborne Toxic Control Measure (ATCM) that phases out the use of PERC in California gradually by 2023. As a result of this regulation, the industry is adopting alternatives. At this stage, at least half the cleaners in California are using alternatives. Major alternatives include hydrocarbon, Green Earth, which is a silicon based solvent called D5, water cleaning processes like wet cleaning and Green Jet, carbon dioxide and Rynex, a glycol ether process (Morris and Wolf, 2005).

PERC is a relatively aggressive solvent which is especially suited for dry cleaning of garments but it may be too aggressive a cleaner for certain delicate garments. Before the production ban on chlorofluorocarbons (CFCs) became effective in 1996, another solvent was used for cleaning a reasonably large portion of the garment stream, perhaps five to 10 percent. The solvent, sold under the tradename of Valclene, was based on CFC-113. This solvent was mentioned in Section 2 as useful for precision cleaning. The advantage of CFC-113 in garment cleaning is that, because it is a gentle solvent, it was used for dry cleaning drapes and other delicate fabrics and trims. Some companies, in anticipation of the production ban, stockpiled CFC-113 so they could continue using the solvent in dry cleaning when necessary. IRTA has identified at least one company, in the movie industry, that still uses stockpiled CFC-113 for cleaning costumes and other delicate garments worn by actors in movies. There may be other companies in the movie industry who do the same.

Many of the alternatives to PERC are very gentle cleaners and they could be used in place of the stockpiled CFC-113. Hydrocarbon is a gentle solvent but it is a VOC whereas CFC-113 is exempt from VOC regulations. This should not be a barrier, however. Carbon dioxide is an especially gentle cleaning method and it could be used in place of CFC-113 dry cleaning. The equipment for using carbon dioxide is expensive, however, and no producers are offering new equipment at this time. Wet cleaning is likely to be too aggressive but Green Jet is a gentle water-based method that might be appropriate if the garments can tolerate water. Green Earth is a very gentle cleaning method but D5, the solvent on which Green Earth is based, has caused cancer in laboratory animals. On balance, hydrocarbon or Green Jet may be the most appropriate methods to substitute for CFC-113.

At some stage, because CFC-113 has not been produced since 1996, the company's stockpile (and other company's stockpiles if there are any) would be depleted, likely before 2020. Even assuming a very large stockpile of five drums of CFC-113 for this application and assuming a density of 13 pounds per gallon for CFC-113, the maximum amount that would be emitted is 3,575 pounds. Based on a GWP for CFC-113 of 5,000 (EPA, 2011), cumulative emissions over the next 10 years could amount to eight thousand metric tons of carbon dioxide equivalent or 0.008 million metric tons of carbon dioxide equivalent.

4.2. Medical Device Manufacturing

Medical device manufacturing is a huge global market and it includes a range of products varying in complexity and applications. Such devices are used for medical purposes in patients, in diagnosis, therapy or surgery.

IRTA worked with a large medical device manufacturer several years ago to find an alternative to CFC-113 for use as a carrier medium in an implantable medical device. The requirements were that the material be low in toxicity and relatively unreactive. The company needed an alternative because of the production ban on ozone depleting substances. Alternatives at the time included HCFCs and HFCs.

The company had stockpiled the CFC-113 in two drums of product. Very little of the CFC-113 was needed for the individual devices and it was anticipated that the stockpiled material would last until the devices became obsolete. Other medical device manufacturers may have also stockpiled CFC-113 for similar purposes. The characteristics of the fully halogenated materials like CFC-113, including its low toxicity and inertness, are the very characteristics that also make it a strong ozone depleting agent and global warming gas. Alternatives for future applications going forward might be HFEs or HFCs with GWPs that are less than about 150.

For purposes of analysis, IRTA assumed that medical device manufacturers in California may have as many as five drums of stockpiled CFC-113 for use in implantable devices or other applications requiring inert substances. On this basis, similar to the analysis for dry cleaning applications above, the emissions of CFC-113 might amount to eight thousand metric tons or 0.008 million metric tons over the next ten years.

4.3. Electrical Equipment Cleaning

Utilities in California must routinely clean electrical equipment at generating stations. Excessive dirt and contamination can cause a flash off in the electrical equipment and possible ignition, explosion and worker injuries. Historically, utilities used CFC-113 and TCA for cleaning electrical devices at generating stations. When production of the two Class I ozone depleting substances was banned, the industry largely substituted HCFC-141b as the cleaning agent. Until 2003, when production of the HCFC was banned, it was still used by many utilities for cleaning electrical equipment. Many suppliers and utilities still have stockpiled HCFC-141b and there may be substantial quantities left today.

IRTA worked on a project, sponsored by EPA, to find alternatives for cleaning electrical equipment (Wolf, 2009). Non-energized electrical equipment was cleaned by many utilities with HCFC-141b although there was no need to use the solvent. IRTA's findings indicated that non-energized electrical equipment can be cleaned with any type of cleaner, including water-based cleaners. It has been tradition to clean energized electrical equipment with substances, like HCFC-141b, without flash points and with low conductivity so workers will not be injured. IRTA's findings indicated that, in some instances, for mechanism cabinets in particular, cleaners with flash points and higher conductivity like acetone, soy-based cleaners and water-based cleaners, can be used for cleaning some types of energized electrical equipment if careful procedures are used. Mechanism cabinets and control panels can be cleaned with carbon dioxide snow. Insulators and other energized electrical equipment can be cleaned with deionized water which is not conductive, media blasting and carbon dioxide pellet blasting.

Utilities in California may have stockpiled as many as 10 drums of HCFC-141b. It is likely that all this stockpiled material will be emitted over the next 10 years. Assuming a density of 10.4 for the HCFC, this amounts to 5,720 pounds. Based on a GWP for HCFC-141b of 630 (EPA, 2011), emissions over the next 10 years would be about one thousand metric tons or 0.001 million metric tons of carbon dioxide equivalent.

4.4. Summary of Stockpiled GHGs

IRTA knows of stockpiles of CFC-113 and HCFC-141b in California that may be emitted over the next 10 years. The applications for this material include a dry cleaning agent for delicate garments, an inert medium in implantable medical devices and a cleaner for energized electrical equipment. Table 4-1 summarizes the GHGs used in these applications, the estimated amount of the stockpile and the cumulative emissions of the GHGs over the next 10 years in carbon dioxide equivalents. Total emissions over the next 10 years for these applications may amount to 0.017 million metric tons of carbon dioxide equivalent. Assuming a uniform emissions profile over the period, annual emissions would be less than 0.002 million metric tons.

Table 4-1
Emission Estimates for Stockpiled GHGs

Application	GHG	Estimated Stockpile (Number of Drums)	Cumulative Emissions (metric tons of CO2e)
Dry Cleaning	CFC-113	5	8,110
Medical Device Manufacture	CFC-113	5	8,110
Electrical Equipment Cleaning	HCFC-141b	10	630
Total			16,850

Section 5. Comparison of Bottom Up Emission Estimates With Alternative Estimates

In Section 2, IRTA developed bottom up emissions estimates for three solvent applications of GHGs for 2010 and projected emissions for 2020 under a BAU scenario. The three applications included film cleaning, vapor degreasing and disk lubing. In Section 3, IRTA developed bottom up bank and emissions estimates for two fire protection applications of GHGs for 2010 and for 2020. These applications included total flooding systems and portable fire extinguishers.

Several years ago, when the Montreal Protocol was being implemented in the U.S., EPA developed a tool for estimating the annual chemical emissions from industrial sectors that have historically used ODSs in their products. Two of the sectors of focus are solvent and fire protection applications (EPA, 2001; Godwin et. al., undated). According to EPA, the model has evolved into a tool for estimating the decline in consumption and emissions of the ODSs and the increase in consumption and emissions of some of the alternatives to ODSs, including HFCs and PFCs. This section examines the estimates of emissions of the alternatives from this model presented by EPA and compares them to the bottom up emissions estimates determined here.

IRTA also worked with two trade associations which provided top down aggregated information for most of the GHGs used in total flooding systems and portable extinguishers. The trade associations collected California specific information from their members for this project. The results are summarized and compared with the bottom up emissions estimates developed here.

5.1. Differences in IRTA Bottom Up Emission Estimates and Other Data Sources

IRTA's bottom up estimates for emissions considered contributions from all GHGs. For solvents, this included HFEs, HFCs, PFCs and HCFCs. For fire protection applications, this included halons, HFCs, PFCs, one HCFC and one fluoroketone. EPA's Vintaging model results apply only to HFCs and PFCs for both solvents and fire protection. The trade association information for fire protection included data on halons, HFCs and PFCs. These factors were considered in the analysis below.

5.2. EPA Vintaging Model Estimates

EPA's Vintaging Model was so named for its method of tracking emissions of annual "vintages" of new equipment that enter into service. It is a bottom up approach and it relies on use and emissions of chemicals based on estimates of the quantity of equipment or products sold each year that contain these chemicals. It also relies on the amount of chemical required to manufacture and/or maintain equipment and products over time.

The Vintaging Model uses data from a variety of sources, including information from EPA programs on alternatives, the United Nations Environment Programme (UNEP) Technical Options Committees, reports, conference proceedings, a variety of trade associations and many of their member companies. In some cases, the information is classified as Confidential Business Information (CBI). As a consequence, the model results are aggregated so that CBI cannot be determined and there is no full public disclosure of the inputs. This "black box" approach means that it is not evident what the assumptions are and how the results are determined. Only the aggregate results can be compared with the IRTA analysis presented here. The Vintaging Model also determines emissions for the U.S. as a whole. California practices are different from practices in the rest of the country in a number of ways. The Vintaging Model results are compared with IRTA's estimates below for solvent and fire extinguishing applications.

5.2.1. Solvent Results Comparison

When the Vintaging Model was first developed, EPA assumed that solvents have a lifetime of one year and that emissions are estimated to be only 10 percent of total solvent usage. What this apparently means is that, of the solvent used in a particular year, only 10 percent is emitted. EPA does admit that emissions may actually be much higher. In fact, emissions from solvent applications are far higher. IRTA relied on emission information from permits to estimate the emissions. If instead, IRTA had relied on usage data, IRTA would have assumed that all the solvent used in a particular year was emitted (a 100 percent emissions estimate). This is because there are really only two destinations for the solvent used in a given year; the solvent is either emitted or it is destroyed.

Considering the applications examined here for the GHG solvents, very little of the solvent is destroyed. The solvent in the still bottoms in the equipment is recycled because of the high value of the solvents and very little is left in the still bottom that is sent out of state for destruction. The solvent in the still bottom is likely to be less than five percent which would suggest an emissions figure of 95 percent. Although the solvents may actually have a life longer than one year, after a steady state usage is established, there is little error in assuming that solvents have a one year life and 100 percent of the solvent is emitted. The results of the Vintaging Model would be expected to be very different from the results presented here.

The Vintaging Model results are presented by EPA for certain HFCs, PFCs and PFPEs. A 2001 EPA report used a figure of 2.1 million metric tons of carbon equivalent as a baseline for 1999 to generate emissions projections for 2000, 2005 and 2010 (EPA, 2001). Million metric tons of carbon equivalent can be converted to million metric tons of carbon dioxide equivalent by multiplying by the ratio 44/12. The 1999 baseline estimate for emissions would be 7.7 million metric tons of carbon dioxide equivalent. The 2010 emission projections are estimated at 2.7 million metric tons of carbon equivalent or 9.9 million metric tons of carbon dioxide equivalent. This estimate is for the U.S. as a whole. The California population accounts for about 11 percent of the total U.S. population. Assuming the business activity that depends on solvents can be apportioned based on population, California emissions from solvent applications would amount to 1.09 million metric tons of carbon dioxide equivalent.

Vintaging Model results for solvents are also estimated in a more recent report (EPA, 2004). In this report, the model assumed that 90 percent of the solvent consumed in solvent applications was emitted. This is a much more reasonable assumption than the earlier assumption described above. In this report, EPA projected worldwide solvent emissions for 2005, 2010, 2015 and 2020. The estimate for 2010 for U.S. emissions is 1.14 million metric tons of carbon equivalent or 4.18 million metric tons of carbon dioxide equivalent. Note that this estimate is significantly lower than the estimate of 9.9 million metric tons of carbon dioxide equivalent in the earlier 2001 report. Making the same assumption as above for the California market leads to an emissions estimate of 0.460 million metric tons of carbon dioxide equivalent.

Vintaging Model results are also estimated in a 2010 EPA report (EPA, 2010). For 2009, the emissions estimate for HFCs and PFCs from solvent applications in the U.S. are 1.3 million metric tons of carbon dioxide equivalent. Note that this estimate is lower than the estimates from both earlier EPA reports. Assuming California accounts for 11 percent of the U.S. emissions, California emissions from solvent applications would be 0.143 million metric tons of carbon dioxide equivalent.

Turning to IRTA's analysis, the solvents used in film cleaning are either HFEs or HCFCs so information on those GHGs are not included in the EPA estimates. Accordingly, it was assumed there is no contribution from film cleaning in the IRTA estimates. IRTA estimated GHG emissions from vapor degreasing applications in 2010, the baseline year, at 0.019 million metric tons of carbon dioxide equivalent. This value included a significant contribution from HCFC-225 and a modest contribution from HFEs. EPA did not include HCFC or HFE solvents in their estimates. Excluding HFEs and HCFC-225 from IRTA's vapor degreasing solvent value results in an emissions estimate of 0.005 million metric tons of carbon dioxide equivalent. Emissions of PFCs from disk lubing operations in Table 2-19 are estimated at 0.007 million metric tons of carbon dioxide equivalent. Summing the contributions from vapor degreasing and disk lubing results in an IRTA HFC and PFC estimate of about 0.012 million metric tons of carbon dioxide equivalent. This is far smaller than the EPA estimates in the 2001, 2004 and 2010 reports. The 2010 report estimate, corrected for California, is an order of magnitude higher than IRTA's estimate. Table 5-1 summarizes the EPA Vintaging Model results and IRTA's estimates.

Table 5-1
Comparison of EPA Vintaging Model and IRTA Solvent Emission Estimates – 2010
(million metric tons of CO2e)

	U.S.	California
EPA 2001	9.9	1.09
EPA 2004	4.18	0.46
EPA 2011	1.3	0.143
IRTA	-	0.012

5.2.2. Fire Protection Results Comparison

In the Vintaging Model, EPA originally assumed that both total flooding and streaming applications have a 15 year life (Godwin et. al., undated). What this apparently means is that total flooding systems and portable fire extinguishers last for 15 years. A report written at a later time indicates the life of total flooding systems to be 20 years and the life of streaming equipment to be 10 years. EPA assumes that emissions each year from total flooding systems are 1.5 percent of the installed base of chemical and that emissions each year for streaming applications are two percent of the installed base (EPA, 2004). For the bottom up approach, IRTA assumed that emissions of HFCs from total flooding systems were lower, at 0.8 percent of the installed base and that emissions from portable systems were four percent.

The Vintaging Model results are presented for PFCs and certain HFCs including HFC-227ea, HFC-236, HFC-125 and HFC-23. Emissions estimates from total flooding and streaming applications are aggregated. An EPA report used 1995 historic estimates of 0.02 million metric tons of carbon equivalent and projected emissions for 2000, 2005 and 2010 (EPA, 2001). For the three years, the report estimates U.S. emissions at 0.2, 0.64 and 1.2 million metric tons of carbon equivalent respectively. Again, million metric tons of carbon equivalent can be converted to million metric tons of carbon dioxide equivalent by multiplying by the ratio 44/12. On this basis, the value for 2010 is 4.4 million metric tons of carbon dioxide equivalent.

A later EPA report estimated the global emissions from fire protection applications but broke out the U.S. emissions. Again, the HFCs and PFCs were aggregated and projected for 2005, 2010, 2015 and 2020 (EPA, 2004). The U.S. values for 2010 and 2020 are 0.65 and 0.89 million metric tons of carbon equivalent respectively. Converting these values leads to 2.38 and 3.26 million metric tons of carbon dioxide equivalent respectively. Note that EPA has revised the 2010 value of 4.4 from the report in 2001 downward to 2.38 million metric tons of carbon dioxide equivalent in the 2004 report.

A third and more recent EPA report estimates 2010 emissions of HFCs and PFCs from fire protection applications at 0.8 million metric tons of carbon dioxide equivalent for the U.S. (EPA, 2010). Note that EPA has again revised the figures downward from the EPA 2004 report. Based on data discussed below, a trade association estimates that sales of HFCs for recharge in fire protection applications into California in 2006 were about three percent of total U.S. sales (HARC, 2010). Making this assumption, and using the estimates from the 2011 EPA report, the Vintaging Model estimates California emissions at 0.024 million metric tons of carbon dioxide equivalent.

As discussed in Section 3, IRTA's emissions estimates for HFCs using the bottom up approach for 2010 are 0.017 million metric tons. The EPA estimates also included emissions of PFCs but IRTA's emissions estimates of PFCs from these applications are negligible so including them would not change the values. Table 5-2 summarizes the EPA and IRTA estimates for emissions from fire protection applications. The EPA value from the Vintaging Model from the 2010 report is 29 percent higher than the value determined by IRTA and the agreement is reasonably good.

Table 5-2 Comparison of EPA Vintaging Model and IRTA HFC Emission Estimates in Fire Protection Applications--2010		
	U.S.	California
EPA 2001	4.4	0.132
EPA 2004	2.38	0.071
EPA 2011	0.8	0.024
IRTA	-	0.017

5.3. Trade Association Estimates

During this project, IRTA worked with the Halon Alternatives Research Corporation (HARC) and the Halon Recycling Corporation (HRC) to make estimates of emissions of GHGs used in fire protection in California. HARC is a nonprofit trade association formed in 1989 to promote the development and approval of environmentally acceptable halon alternatives (www.HARC.org). HRC is a voluntary nonprofit trade association formed by concerned halon users and the fire protection industry to support the goals of the environmental community and the U.S. EPA (www.Halons.org).

HARC overseas a voluntary data collection effort, called the HFC Emissions Estimating Program or HEEP (Cortina and Senacal, undated). Under this program, HARC collects data on sales of HFC and PFC fire extinguishing agents for recharge as a method of estimating annual emissions of HFCs and PFCs. The HEEP program defines emission as the quantity of agent sold for the purpose of “recharge” of fire suppression containers. This approach was adopted because recharge is only required after an agent has been discharged or emitted from equipment. Thus, the recharge sales should be a proxy for emissions. The parties reporting the recharge information include: 1) equipment manufacturers or distributors that perform the first fill of original equipment and also recharge equipment and 2) agent suppliers or equipment manufacturers that sell to distributors that only perform recharge. HARC acts as an independent party for collecting the information. The data for the individual agents are weighted by their GWPs and aggregated.

In April 2010, HARC issued a HEEP report which summarized the data collection for the period 2002 through 2008 for the U.S. as a whole (HEEP, 20010). In 2002, HARC sent a survey to companies that would be possible reporting parties. A final list of 23 reporting parties was identified. Data collection forms were sent to the 23 reporting parties asking for the pounds of HFC and PFC fire protection agents sold for recharge in the years 2002 through 2008. Table 5-3 summarizes the data that were collected for the period. The information included HFC-23, PFC-14, HFC-125, HFC-134a, HFC-227ea, HFC-236fa and PFC-3-1-10. These agents are or have been used in total flooding systems and/or streaming applications. Each of the agents was weighted by its GWP and the values were aggregated in the third column of Table 5-3.

Table 5-3 HEEP Report Summary for 2002 Through 2007		
Year	Companies Reporting	Sales for Recharge (million metric tons of CO2e)
2002	22	0.53
2003	20	0.523
2004	21	0.625
2005	21	0.681
2006	21	0.589
2007	21	0.656
2008	21	0.622

HARC, as a practice, does not collect data for individual states. For this project, HARC did make an exception, however, and the organization collected confidential data from 16 companies, including 12 equipment manufacturers and four recyclers, on the number of pounds of four different agents sold into California for fire protection in 2006 and 2009. The agents were HFC-23, HFC-125, HFC-227ea and HFC-236fa. The information for each agent was weighted according to its GWP, combined and presented in terms of carbon dioxide equivalent emissions. HARC has no information on whether these agents were actually installed in equipment in California, or whether agents sold into a different state may have been installed in equipment in California. In spite of these limitations, the data are very useful for developing a top down approach to estimating emissions (HARC, 2011).

Table 5-4 summarizes the data collected by HARC expressed in terms of million metric tons of carbon dioxide equivalent emissions. The GWPs used for each of the HFCs are 11,700 for HFC-23, 2,800 for HFC-125, 2,900 for HFC-227ea and 6,300 for HFC-236fa.

Table 5-4 HARC Data for Fire Protection HFCs Sold into California (million metric tons of CO2e)			
2006		2009	
Sales for New Installations	Sales for Recharge of Existing Equipment	Sales for New Installations	Sales for Recharge of Existing Equipment
0.306	0.018	0.299	0.011

The HRC does not have a program for collecting data. Rather, the organization was established to facilitate halon recycling, determine critical uses and act as an information clearinghouse for halon recycling. HRC also worked with IRTA to collect sales data for halons for fire protection in California. In this case, confidential data were collected from five halon recyclers that are members of HRC. There is one additional recycler that is not a member. HRC collected the number of pounds of Halon 1211 and Halon 1301 sold into California in 2008 and 2009. HRC has no information on whether halons sold into a different state may have been installed in equipment in California (HRC, 2011).

Table 5-5 summarizes the data collected by HRC. In this case, the data are presented as pounds of agent sold into California. Because halons are generally not used in new systems, the HRC sales data effectively are emissions data.

Table 5-5 HRC Data for Fire Protection Halons Sold into California (pounds)			
2008		2009	
Halon 1211	Halon 1301	Halon 1211	Halon 1301
8,850	140,707	755	100,955

5.3.1. Fire Protection Comparison of HFC Emission Estimates

The two HFCs used in total flooding systems are HFC-227ea and HFC-125; the HFC used in portable extinguishants is HFC-236fa. The HFC data provided by HARC for 2006 and 2009 for recharge are 0.018 and 0.011 million metric tons of carbon dioxide equivalent emissions respectively, according to Table 5-4. This represents the California emissions of the combined HFCs for those years. HARC did not include data on HCFCs so there is no information on the Halotron I emissions. HARC also did not include data on PFCs so there is no information on the PFC emissions from total flooding systems. In the bottom up analysis, IRTA determined there are no PFCs and no HFC-23 used in portable extinguishers.

The HARC data do not include emissions from recycling that occurs in California. The aggregated HARC data represent emissions of only three HFCs, HFC-227ea, HFC-125 and HFC-236fa. IRTA's estimate for 2010 from Table 3-6 indicates that emissions of HFC-227ea from total flooding systems are 14,211 metric tons of carbon dioxide equivalent emissions, exclusive of emissions from recycling operations. Emissions of HFC-125 from total flooding systems were 1,525 metric tons of carbon dioxide equivalent, exclusive of recycling emissions. IRTA's estimates for 2010 for HFC-236fa from portable fire extinguishers are 1,441 metric tons of carbon dioxide equivalent emissions from Table 3-20. The IRTA estimate for total 2010 emissions of HFCs from fire protection equipment using the bottom up figures is 17,177 metric tons of carbon dioxide equivalent or about 0.017 million metric tons of carbon dioxide equivalent.

The IRTA bottom up emission estimates are summarized in Table 5-6 and compared with the HARC HFC estimates. The IRTA total is higher than the figure of 0.011 million metric tons of carbon dioxide equivalent emissions provided by HARC for 2009 and is lower than the figure of 0.018 million metric tons of carbon dioxide equivalent emissions provided by HARC for 2006. Taking into account that there may be year to year variations, the bottom up estimate is within the range of the 2006 and 2009 HARC values.

Table 5-6 Comparison of IRTA and HARC HFC Emission Estimates (metric tons of CO_2e)			
	IRTA	HARC	
	2010	2006	2009
HFC-227ea	14,211	-	-
HFC-125	1,525	-	-
HFC-236fa	1,441	-	-
Total	17,177	18,000	11,000

5.3.2. Fire Protection Comparison of Halon Emission Estimates

The HRC data for the halons are information provided by recyclers for sale into California. There are virtually no new halon total flooding systems and only a few new halon fire extinguishers sold each year. HRC sales data, which largely represents emissions data, for Halon 1211 in 2008 and 2009 are 8,850 and 755 pounds respectively. HRC sales data for Halon 1301 in 2008 and 2009 are 140,707 and 100,955 respectively. One source estimates that about 75 percent of Halon 1301 sold into California by HRC members goes to aviation rather than total flooding system applications and that 20 to 50 percent of the Halon 1211 sold into California by HRC members is used for aviation applications. Accepting the 75 percent estimate for Halon 1301 and the midpoint of 35 percent for Halon 1211, Table 5-7 presents the amount of Halons sold into non-aviation applications.

Table 5-7 HRC Data for Fire Protection Halons Sold into Non-Aviation Applications in California (pounds)			
2008		2009	
Halon 1211	Halon 1301	Halon 1211	Halon 1301
5,753	35,177	491	25,239

Table 5-8 compares the HRC and IRTA Halon 1211 emission estimates. In the bottom up analysis, IRTA estimated 2010 emissions of Halon 1211 at 7,560 pounds from Table 3-20. This is higher than the HRC estimate for 2008 of 5,753 and much higher than the HRC estimate for 2009. If the estimate for the amount of Halon 1211 devoted to aviation applications is actually only 20 percent rather than 35 percent, the 2008 HRC estimate would be higher, at 7,090 pounds. This agrees well with the IRTA 2010 estimate of 7,560 pounds.

Table 5-8 Comparison of IRTA and HRC Halon 1211 Emission Estimates (pounds)		
IRTA	HRC	
2010	2008	2009
7,560	5,753	491

Table 5-9 compares the HRC and IRTA Halon 1301 emission estimates. In the bottom up analysis, IRTA estimated 2010 emissions of Halon 1301 at 12,000 pounds exclusive of emissions from recycling operations. This is substantially lower than the HRC values. There are two possible explanations for the discrepancy in the Halon 1301 data. First, a much higher percentage of the Halon 1301 sold into California may go to aviation applications or may be sent out of state again for use in aviation or non-aviation applications. The percentage would have to be 88 to 91 percent devoted to aviation and out of state applications to make the values consistent. Second, there could be many more total flooding systems in California containing Halon 1301 and/or emissions of the material would have to be much larger than those estimated here. In Table 3-2, IRTA estimated the number of Halon 1301 total flooding systems in California at 1,000. To agree with the Halon 1301 2009 value in Table 3-25, there would need to be between about 2,000 and 3,000 total flooding systems in California containing the GHG. This does not seem reasonable since there are only an estimated 5,000 total systems. If the emission factor accounts for the discrepancy, Halon 1301 emissions from total flooding systems would have to be more than eight percent of the installed base. This also is not reasonable.

Table 5-9
Comparison of IRTA and HRC Halon 1301 Emission Estimates (pounds)

IRTA	HRC	
2010	2008	2009
12,000	35,177	25,239

It is likely that a combination of factors explains the discrepancy. The percentage of Halon 1301 that goes to aviation or is shipped back out of state is probably higher than 75. There may be a few more Halon 1301 total flooding systems but the installer IRTA worked with is not convinced there are many more than 5,000 total flooding systems in California. Emissions from the Halon 1301 systems could be much higher. If the emissions actually are much higher, the Halon 1301 systems will be decommissioned over the next 10 years and only newer less emissive systems will still be in use.

5.4. Comparison of IRTA, EPA and Trade Association Emission Estimates For Fire Protection

Based on data collected under HEEP, HARC estimates that sales of HFCs for recharge into California in 2006 were about three percent of total U.S. sales (HARC, 2011). Making this assumption, and using the estimates from the 2010 EPA report, the Vintaging Model estimates HFC California emissions at 0.024 million metric tons of carbon dioxide equivalent. As discussed in Section 3, IRTA's emissions estimates for HFCs using the bottom up approach for 2010 are 0.017 million metric tons of carbon dioxide equivalent. The EPA estimates also included emissions of PFCs but IRTA's emissions estimates of PFCs from these applications are negligible so including them would not change the values.

Table 5-10 compares the IRTA, HARC and EPA Vintaging Model HFC emission estimates. The value determined by IRTA is 29 percent lower than the EPA value from the Vintaging Model. The EPA value is also higher than the value for HFC emissions provided by HARC. In this case, however, the agreement of the Vintaging Model, the IRTA and the HARC estimates is reasonably good.

Table 5-10
Comparison of IRTA, HARC and EPA HFC Emmision Estimates for Fire Protection Applications
(million metric tons of CO_2e)

IRTA	HARC		EPA
2010	2006	2009	2010
0.017	0.018	0.011	0.024

Section 6. Results and Conclusions

This project focused on developing an emission inventory for certain categories of GHGs with high GWPs. GHGs of focus were HFCs, PFCs and ozone depleting substances like CFCs, HCFCs and halons. The categories that were addressed were three solvent applications including film cleaning, vapor degreasing and disk lubing; two fire protection applications including fixed total flooding systems and portable fire extinguishers; and three other uses of stockpiled GHGs including dry cleaning, medical device manufacturing and energized electrical equipment cleaning.

The analysis involved developing a 2010 emission inventory for the solvent and fire protection applications, a projection of 2020 emissions assuming a business as usual scenario and two alternative emission projection scenarios that vary depending on the characteristics of the application. For the fire protection applications, the analysis also focused on developing a 2010 estimate of the bank of GHGs and their major alternatives and projections of the bank under a business as usual and alternative scenarios for 2020. A cost analysis and comparison was presented for the major applications to evaluate the feasibility of using lower GWP and non-GHG alternatives. The results are summarized below in more detail.

6.1. Baseline and Projected Emissions—Solvent Applications

The GHG solvents used in film cleaning today are HCFC-225 and various HFEs. Emissions are projected to decline from 1,907 to 150 metric tons of carbon dioxide equivalent between 2010 and 2020. One reason for the decline is that HCFC-225 production will be banned because the solvent contributes to ozone depletion. Since it has a higher GWP than the HFEs, the weighted emissions will decline. Another more pronounced reason for the decline is that the need for film cleaning will be reduced dramatically because of the move toward digital technology. Alternatives to the GHG film cleaning solvents are available and cost effective. One of the alternatives, IPA, is fairly low in toxicity but is a VOC. The other alternative, PERC, is a carcinogen. IPA could be used for the small remaining requirement for film cleaning in 2020. Assuming a constant uniform annual decline in the weighted emissions, in the absence of regulation, cumulative emissions of HCFC-225 and HFE from this application would amount to about 9.4 thousand or 0.009 million metric tons of carbon dioxide equivalent over the next ten years.

A range of GHG solvents and blends of GHG solvents are used in vapor degreasing in California. The major GHG solvent used by the industry today is HCFC-225. Other GHG solvents used in the application include HFEs and HFC-4310. There will be a decline in emissions of GHG solvents in vapor degreasing over the next 10 years. The major reason for the decline is that production of HCFC-225 will be banned and the solvent has a relatively high GWP. Many of the HCFC-225 users will convert to non-GHG alternatives. Emissions are expected to decline from 19,420 to 3,289 metric tons of carbon dioxide equivalent between 2010 and 2020. Options for reducing emissions include converting to a non-GHG alternative or purchasing an airless/airtight degreaser. Both options are cost effective. Water-based cleaners can be substituted in many cases but many users are unwilling to conduct the testing needed to determine whether an alternative process would be suitable. Assuming a constant uniform annual decline in the weighted emissions, in the absence of regulation, cumulative emissions from this application would be about 105 thousand or 0.105 million metric tons over the next ten years.

In disk lubing operations, GHG solvents act as a carrier medium for depositing a coating on the disks. One PFC and HFEs are used for this purpose. Only two companies in California perform this operation and emissions are low. Because the PFC has a very high GWP, however, weighted emissions are high. Emissions of GHG solvents from disk lubing operations are 7,141 metric tons of carbon dioxide equivalent in 2010 and they are expected to remain at this level until 2020. Alternatives to the PFC are available and they include HFEs and HFC-4310 which have lower GWPs. The company using the PFC could adopt one of these alternatives and weighted emissions would be substantially lower. In the absence of regulation, cumulative emissions from this application would amount to about 71 thousand or 0.071 million metric tons of carbon dioxide equivalent over the next nine years.

Table 6-1 summarizes the baseline 2010 emissions, the business as usual projected emissions in 2020 and the cumulative emissions over the ten year period from the three solvent applications. The values show that cumulative emissions over the ten year period from solvent applications will amount to about 0.186 thousand or about 0.2 million metric tons. The biggest contributor to the cumulative emissions is vapor degreasing.

Table 6-1
Baseline, Projected and Cumulative Emissions from Solvent Applications
(metric tons of CO2e)

Application	2010 Baseline Emissions	2020 BAU Scenario Emissions	Cumulative Emissions
Film Cleaning	1,907	150	9,406
Vapor Degreasing	19,420	3,289	105,480
Disk Lubing	7,141	7,141	71,410
Total	28,468	10,580	186,296

CARB has several options for reducing emissions from solvent applications. Emissions from film cleaning will decline substantially over the next ten years because of the move to digital technology. As discussed in Section 2, the SCAQMD adopted a regulation that required solvents used in open top vapor degreasers to have a VOC content of 25 grams per liter or less. Companies could use higher VOC content solvents but they would have to use them in airless/airtight vapor degreasers. If other air districts were to adopt a similar regulation, users would either switch away from the GHG solvents that remained on the market after the ban of HCFC-225 or they would purchase an airless/airtight degreaser. The other GHG solvents, the HFEs and HCFC-4310, do not perform well unless they contain another more aggressive VOC solvent. Conversion to non-GHG alternatives or use of an airless/airtight degreaser would both result in reductions in cumulative emissions from vapor degreasing over the next decade. CARB could initiate a statewide measure and the San Diego County APCD and the Bay Area AQMD could adopt regulations to implement the change.

An option for reducing emissions from disk lubing would be to prohibit the use of PFCs in the process. The one company using a PFC could use an HFE or even HFC-4310 just as effectively. Cumulative emissions from disk lubing would be negligible over the next decade under this policy.

6.2 Baseline and Projected Bank and Emissions—Fire Protection Applications

The GHG agents used in total flooding systems today include Halon 1301, HFC-227ea, HFC-125, FK-5-1-12 and PFCs. The bank of GHGs in this application in 2010 is 2,929,124 or about three million metric tons of carbon dioxide equivalent. The size of the bank in 2020 under a business as usual scenario is projected to decline to 1,573,975 or about 1.6 million metric tons of carbon dioxide equivalent. Emissions from total flooding systems are estimated at 53,488 metric tons of carbon dioxide equivalent in 2010. Emissions under the business as usual scenario are expected to decline in 2020 to 12,592 metric tons of carbon dioxide equivalent. The major reason for the decline in the bank and in emissions is that there will be no Halon 1301 and PFC systems in 2020. Halon 1301 and PFCs have high GWPs. Another reason for the decline is that companies are moving away from the HFCs which have relatively high GWPs to FK-5-1-12 and not in kind alternatives like inert gases. These alternatives appear to be viable and they are reasonably cost effective. Suppliers are trying to develop other alternatives with very low GWPs and some of these may enter the market over the next few years. In the absence of regulation, cumulative emissions from total flooding systems will amount to 368,064 or 0.3 million metric tons of carbon dioxide equivalent over the next ten years.

The GHG agents in portable fire extinguishers include Halon 1211, Halotron I and HFC-236fa. The 2010 bank of portable GHG extinguishants is estimated at 152,123 metric tons of carbon dioxide equivalent. It is expected to decline by 2020 under a business as usual scenario to 118,739 metric tons of carbon dioxide equivalent. Baseline 2010 emissions for this application are estimated at 6,088 metric tons of carbon dioxide equivalent. Under a business as usual scenario, emissions are projected to decline to 4,750 metric tons of carbon dioxide equivalent by 2020. A major reason for the decline in the size of the bank and emissions is that the use of Halon 1211, which has a high GWP, will decline substantially over the period. Halotron I, which is a blend containing an HCFC which causes ozone depletion will be phased out but the effects will primarily be felt after 2020. Alternatives available today include various not-in-kind materials like carbon dioxide and dry chemicals. To some extent, users are adopting these alternatives because of their lower cost. Suppliers are working on alternatives that have low GWPs and these may be available over the next several years. Without regulations, cumulative emissions from portable extinguishers will total 12,042 metric tons or 0.012 million metric tons of carbon dioxide equivalent.

Table 6-2 summarizes the bank, emissions and cumulative emissions for total flooding systems and portable extinguishers. The values show that the cumulative emissions from fire protection applications over the next decade is estimated at 363 thousand or about 0.4 million metric tons of carbon dioxide equivalent. Cumulative emissions from total flooding systems are nearly six times higher than cumulative emissions from portable extinguishers.

Table 6-2 Baseline, Projected and Cumulative Emissions from Fire Protection Applications (metric tons of CO2e)					
Application	2010 Baseline		2020 BAU Scenario		
	Bank	Emissions	Bank	Emissions	Cumulative Emissions
Total Flooding Systems	2,929,124	53,488	1,573,975	12,592	309,952
Portable Extinguishers	152,123	6,088	118,739	4,750	53,521
Total	3,081,247	59,576	1,692,714	17,342	363,473

CARB has several options for reducing emissions from fire protection applications. One option would be to require immediate decommissioning of all Halon 1301 total flooding systems and Halon 1211 portable systems and require conversion to lower GWP or non-GHG alternatives. There are two problems with this option. First, decommissioning the systems might result in higher emissions over the short term than if use of the halons is allowed to decline gradually over time. The decommissioning process itself could be mishandled because so many systems would have to be processed. Furthermore, some companies might simply vent the systems to avoid the problems of designing and purchasing new systems to use the alternatives. Presumably, the halons would be sent to recyclers and would be sold for critical uses like the aviation industry. Because they would continue to be used, emissions from their use in would continue. Second, CARB might decide that, rather than recycle the halons, they should be destroyed so they would not ever be emitted and this could present issues. The spent halon could be classified as hazardous waste in California and there are no facilities permitted to process them in the state. The halons would have to be shipped out of state for destruction and there could be criticism for passing off the problem to other states.

Other options might involve a requirement for all new systems to use the low GWP alternatives. This would push new systems to inert gases and FK-5-1-12 in total flooding applications. Once the major restriction on Halotron I becomes effective in 2015, there would be no low GWP alternative in portable extinguisher applications. CARB would have to rely on the market to develop and introduce low GWP alternatives before the ban.

6.3 Cumulative Emissions of Stockpiled Materials

IRTA is aware of stockpiled CFC-113 for dry cleaning of movie costumes, CFC-113 for use in medical devices and HCFC-141b for use in cleaning energized electrical equipment. Cumulative emissions of the stockpiled GHGs are estimated at 0.017 million metric tons. The only way to prevent the emissions would be to require the material to be destroyed. This destruction would have to be performed at an out of state facility.

6.4. Comparison With Other Data Sources

The bottom up solvent emission estimates determined here were compared with the EPA Vintaging Model estimates published and updated over the last decade. IRTA's emission estimates for HFC and PFC solvents in California are more than an order of magnitude less than the most recent EPA Vintaging Model estimates.

IRTA's emission estimates from fire protection applications were compared with EPA Vintaging Model estimates and estimates provided by two trade associations, HARC and HRC. The HARC data and the IRTA estimates for HFC emissions are in reasonable agreement and the EPA value is somewhat higher than both of the other estimates. IRTA's estimates for Halon 1211 emissions are higher than the HRC data and IRTA's emission estimates.

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